X-805-74-176
PREPRINT

NASA TM X- 70710

TRACKING AND DATA RELAY SATELLITE SYSTEM (TDRSS) USERS' GUIDE

(NASA-TM-X-70710) TRACKING AND DATA RELAY SATELLITE SYSTEM (TDRSS), USERS' GUIDE (NASA) 79 p HC $7.00 CSCL 17I

N74-29499

Unclas
G3/07 54797

JUNE 10, 1974

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

TRACKING AND DATA
RELAY SATELLITE SYSTEM
(TDRSS)
USERS' GUIDE

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PREFACE

This document provides a brief introduction to the Tracking and Data Relay Satellite System (TDRSS) and is oriented to potential system users. It will be updated and expanded periodically to effect changes in TDRSS planning and to include additional TDRSS user-oriented data. Current detailed planning information is available through the TDRSS Project Office, Code 805, Goddard Space Flight Center, Greenbelt, Maryland.

The following TDRSS performance parameters are presently under consideration and will be included in revisions to this document as they are defined:

a. Multiple-access system chip rates.

b. PN code type and lengths.

c. Single-access S-band return link parameters.

d. S-band beacon parameters.

The TDRSS performance parameters specified in this document are based upon the TDRS configuration defined by the definition phase study and represents the minimum level of service which will be provided by the TDRS system. Present plans specify the acquisition of the system by a leased service arrangement which may result in a hardware configuration that differs from that which is contained within this document, however the specified performance parameters will be supplied, as a minimum, by the resulting system.

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1. TDRSS CONCEPT AND CHARACTERISTICS

1.1 The Tracking and Data Relay Satellite System (TDRSS) concept consists of two geosynchronous relay satellites, 130 degrees apart in longitude (see figure 1), and a ground terminal centrally located in the continental United States. Additionally, the system includes two spare satellites: one in orbit, and one in configuration for a rapid replacement launch. The payload of each Tracking and Data Relay Satellite (TDRS) is the telecommunications service system which relays communication signals between low earth-orbiting user spacecraft and the TDRSS ground terminal. A "bent-pipe" concept is used in the design of the telecommunications service system (i.e., all communication signals received at the TDRS are translated in frequency and retransmitted).

1.2 The telecommunications link from the ground terminal to the TDRS to the user is called the forward link and will be used to carry user command data, tracking signals, and voice transmissions. The link from the user to the TDRS to the ground terminal is called the return link and will be used to carry user telemetry data, return tracking signals, and voice. Both the forward and return links consist of a space-to-space link between the TDRS and the user, and a space-to-ground link between the TDRS and the TDRSS ground terminal (see figure 2).

1.3 Each TDRS provides the following two types of space-to-space communication links:

a. Multiple-access System. One 10-element* S-band phased array antenna system to support the forward link (command link) of 20 users (time shared), and one 30-element S-band phased array antenna to support the return link (telemetry link) of 20 users simultaneously. The spacecraft supported by this system are called Multiple-access (MA) users.

b. Single-access System. Two 3.8 meter* parabolic antennas, each operating at both S- and Ku-band. This configuration is called a single-access system because each antenna will normally support one user at a time. However, each antenna can support two users simultaneously (one at S-band and one at Ku-band) provided both users are within the beamwidth of the antenna. The user spacecraft supported by this system are called Single-access (SA) S- or Ku-band users.

2. THE POST 1978 STDN

2.1 With the implementation of the TDRSS, the post 1978 STDN will consist of two subnets: the TDRSS subnet, consisting of the TDRS's and the TDRSS ground terminal, and the ground site subnet, consisting of a six- to eight-site subnet of the STDN planned for 1976. The ground site subnet will include (by current planning) the following site locations: Goldstone, Madrid, Orroral, Alaska, Merritt Island, Rosman, Bermuda (launch only), and Tananarive (launch only).

*See Preface.

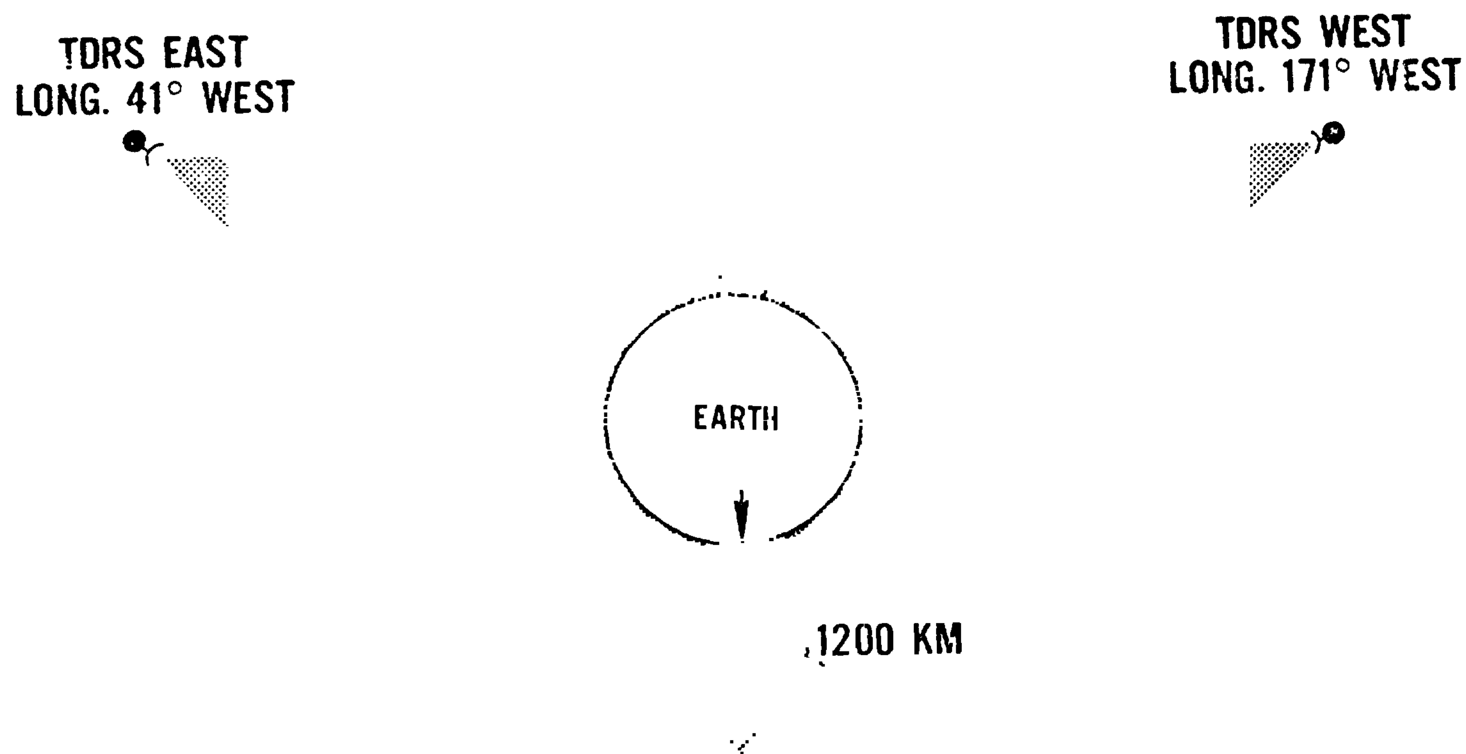


Figure 1. Two-satellite TDRSS

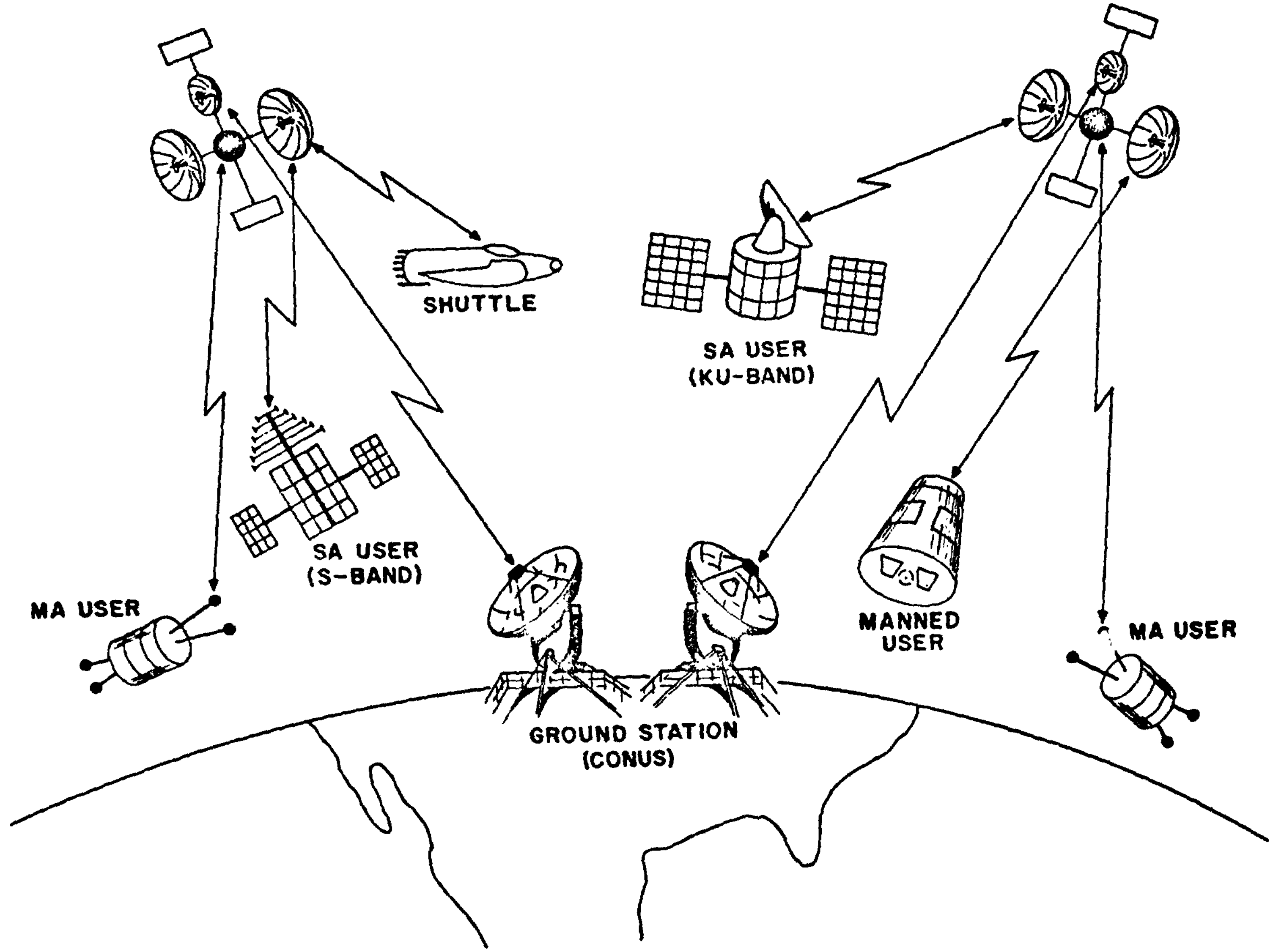


Figure 2. Two-satellite TDRSS Concept

2.2 Both subnets will present the same interface to the STDN user and both can provide telemetry, command, and tracking to any user. The TDRSS subnet will provide the primary support to low-earth orbit users while the ground site subnet will provide primary support to mid- and high-altitude users.

3. TDRSS SUPPORT CAPABILITIES

3.1 GENERAL

Paragraphs 3.2 through 3.5 briefly describe the TDRSS support capabilities. These capabilities are based on the following assumptions:

a. The user vehicle communications terminal is sufficient for the data rate transmitted. (The user transmit terminal requirements as a function of data rate are given in figure 3 and appendix A.)

b. The transmitted or received signal characteristics are compatible with TDRSS.

c. All multiple-access system links must be digital.

d. Each multiple-access system user must use the minimum return link EIRP required for transmission of his data rate to minimize interference with other MA users.

3.2 TDRSS FREQUENCY PLAN

The TDRSS frequency plan is shown in summary in figure 4 and by frequency band in figures 5 through 7.

3.3 MULTIPLE-ACCESS SYSTEM

3.3.1 FORWARD (COMMAND) LINK

a. Antenna	-	10-element** phased array, 23-dB gain, single steered beam per TDRS.
b. Frequency	-	2106.4 MHz, all users on same frequency.
c. Bandwidth	-	5 MHz.
d. TDRSS signal EIRP*	-	34 dBw peak.
e. Duty factor	-	Continuous.
f. User command	-	Time shared between users.
g. Command rate	-	100 to 1000 b/s.
h. Modulation	-	PN spread spectrum (for chip rate, refer to table 1). PSK (±90°), biphase.

*EIRP in direction of user.
**See Preface.

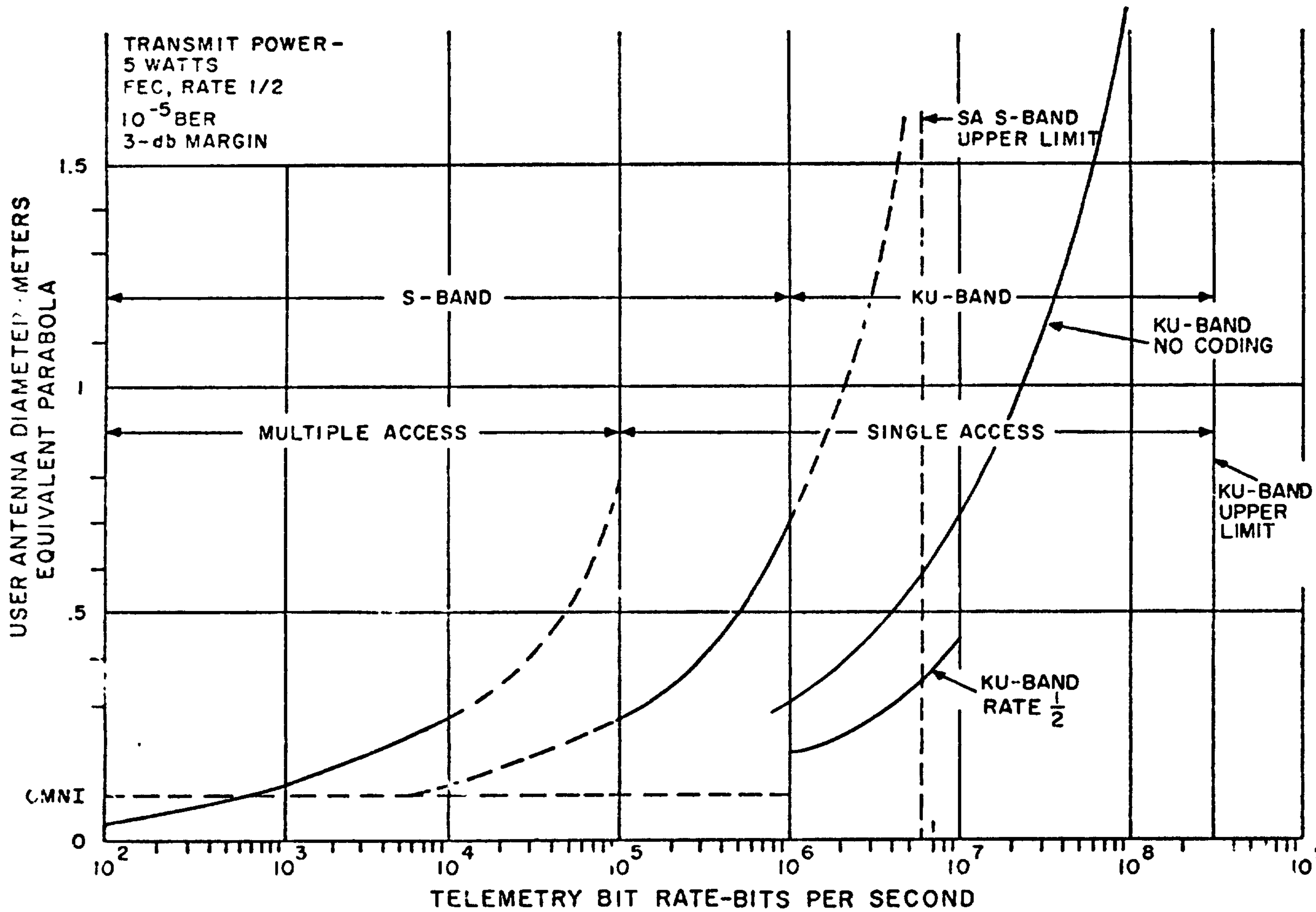


Figure 3. User Antenna Size vs. Telemetry Bit Rate

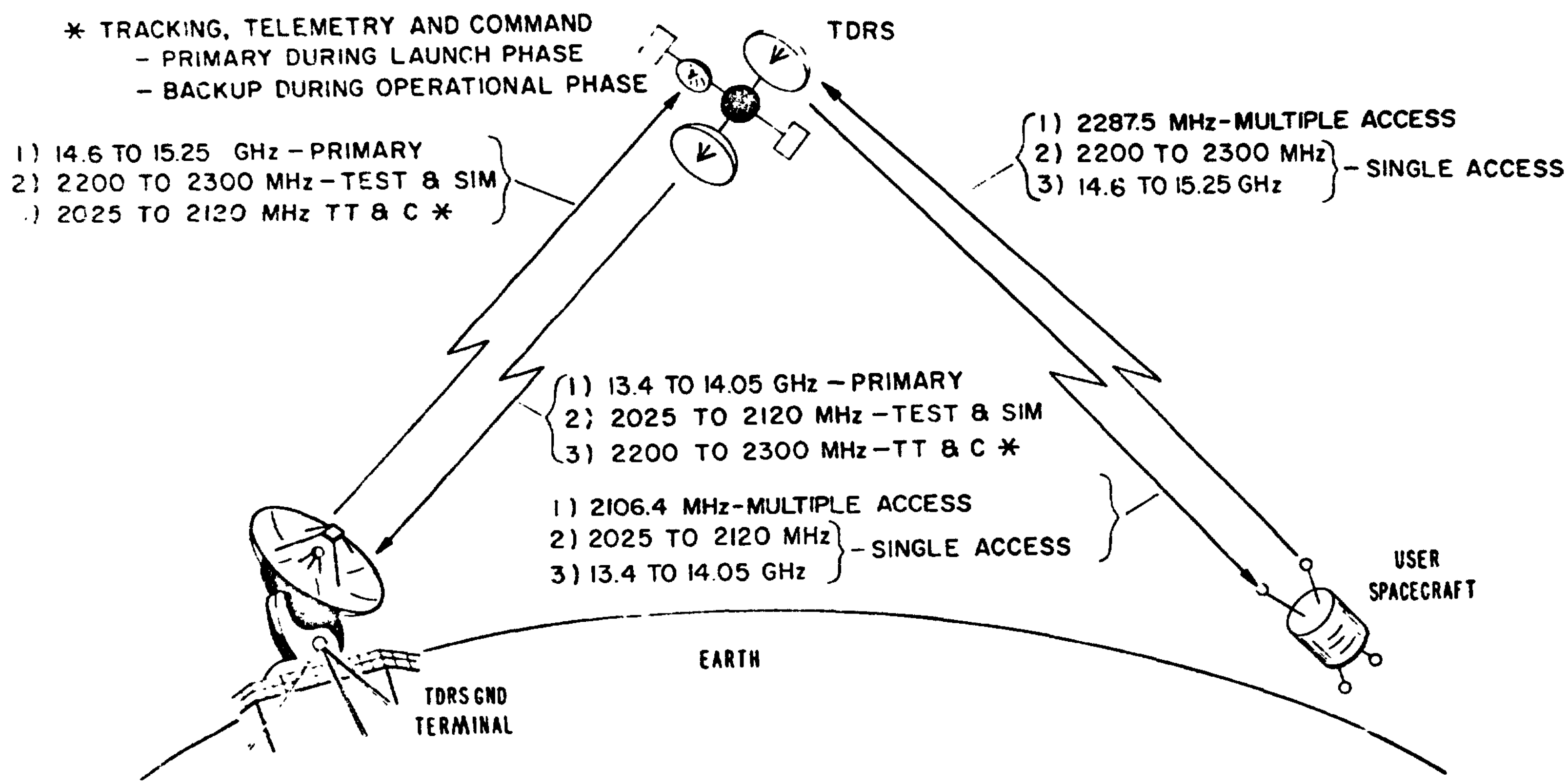


Figure 4. TDRSS Frequency Plan

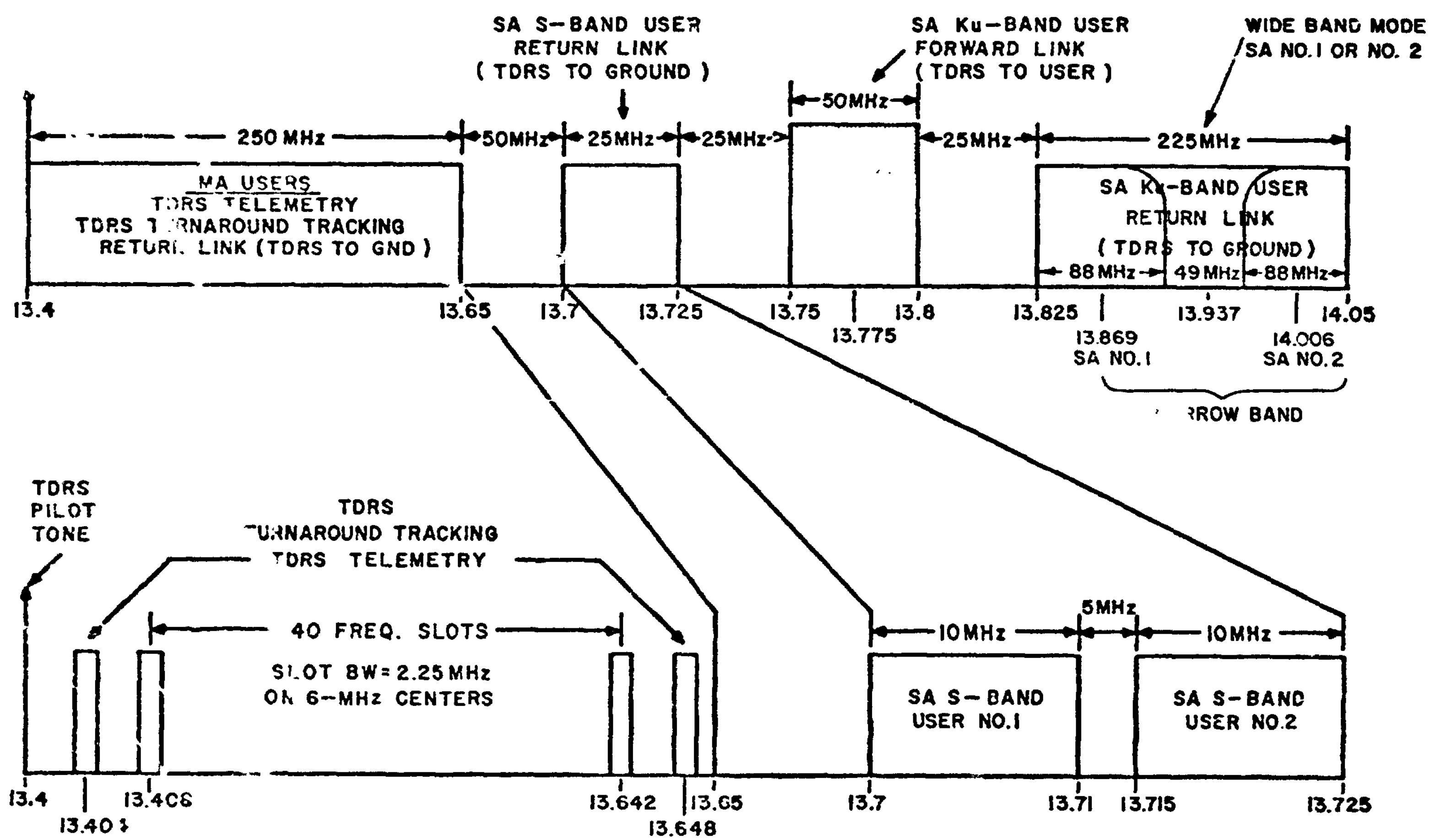


Figure 5. TDRS Ku-band Transmit Frequency Plan

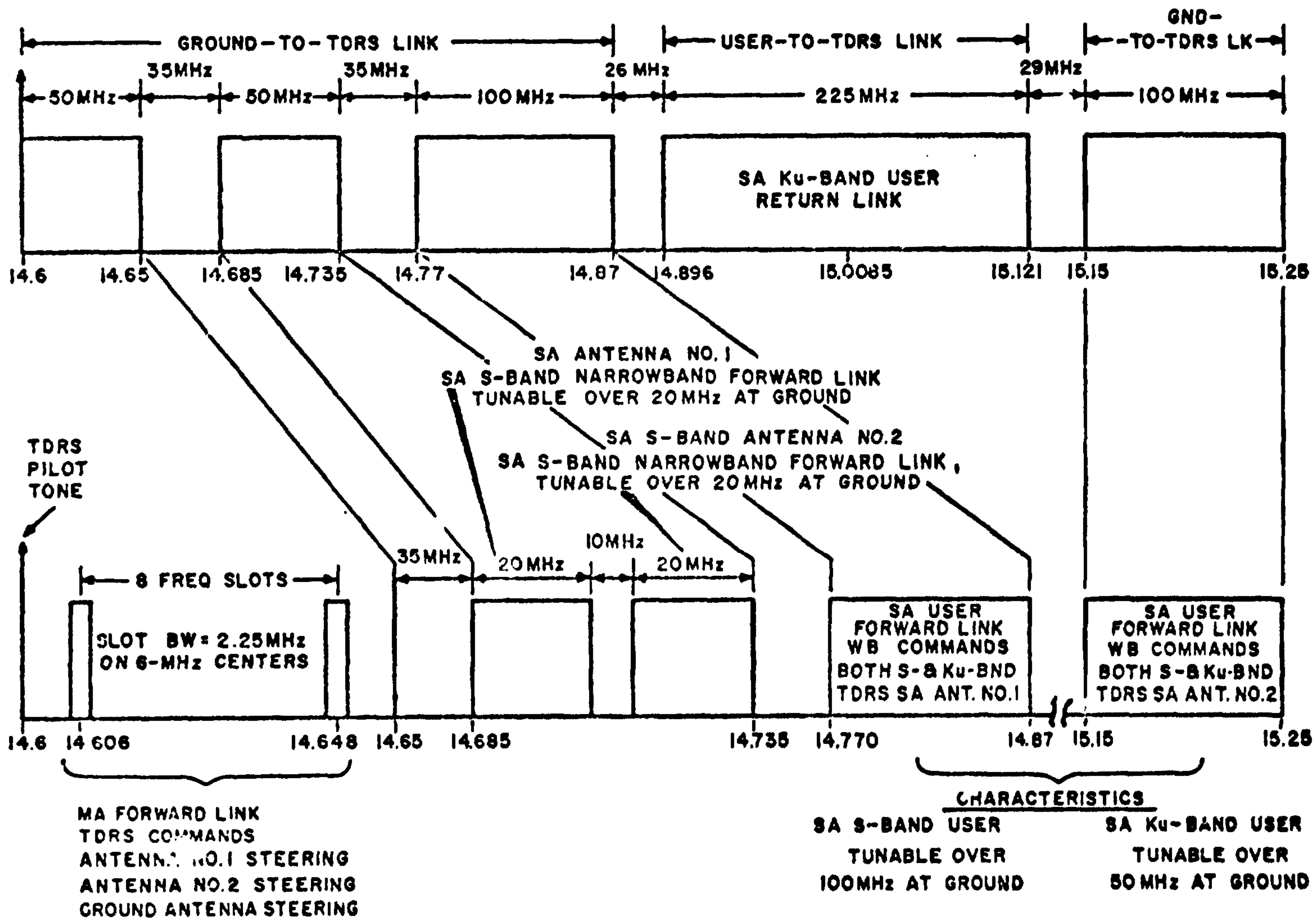
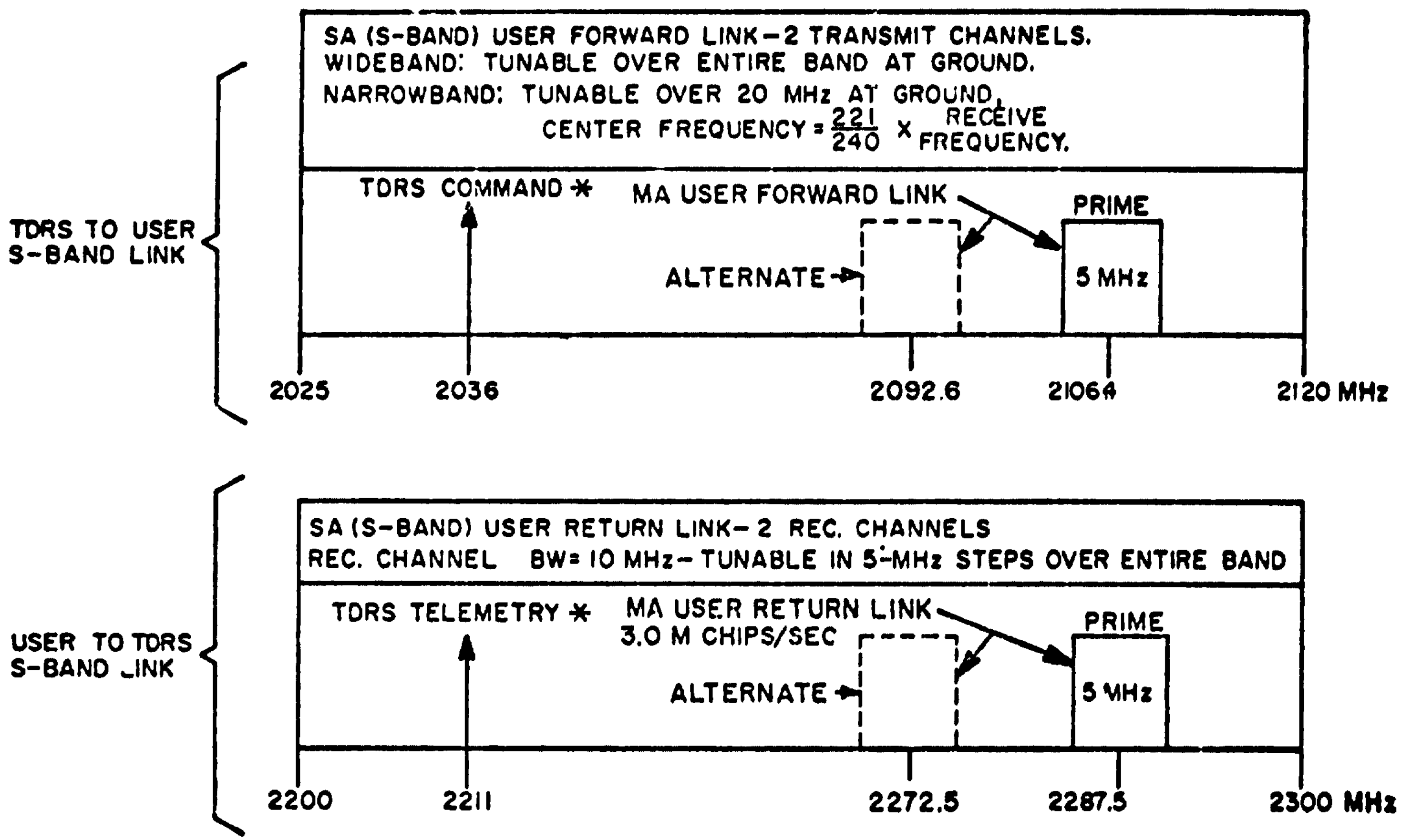


Figure 6. TDRS Ku-band Receive Frequency Plan



* TDRS TELEMETRY & COMMANDS
- PRIME DURING LAUNCH PHASE
- BACKUP DURING OPERATIONAL PHASE

Figure 7. TDRS S-band Frequency Plan

i. Operation - All users on same command frequency, users separated by user unique codes, beam steered to desired user for duration of command and/or tracking sequence.

j. Code type - Gold, length to be defined (≈ 2000 bits/code).

3.3.2 RETURN (TELEMETRY) LINK

a. Antenna - 30-element phased array*(gain 28 dB).

b. Frequency - 2287.5 MHz (all users on same frequency).

c. Bandwidth - 5 MHz.

d. Array beam forming - All element combining/beam forming performed at ground terminal. Separate array beam formed for each user simultaneously.

e. Return link signal characteristics - Code division multiplex/PRN spread spectrum modulation (tentative value 3.0 Mch/s). PSK (±90°), biphase.

f. Maximum single user telemetry rate - 48 kb/s.

g. Average user telemetry rate ≈ 10 kb/s - Each user's supportable data rate is a function of the number, EIRP, and data rates of the other simultaneously-supported users.

h. Support duration/user - Continuous when in view of either TDRS (at least 85 percent of each low earth orbit).

i. Data handling - Data returned to user in real time.

j. Code type - Gold, length to be determined (≈ 2000 bits).

3.4 SINGLE-ACCESS SERVICE

3.4.1 GENERAL

Each single-access system can operate at S-band (command and telemetry), Ku-band (command and telemetry), or both simultaneously. There are two single-access systems per TDRS.

*See Preface.

3.4.2 S-BAND SINGLE-ACCESS SERVICE

3.4.2.1 Forward (Command) Link

a. Antenna	-	3.8-meter* diameter parabolic reflector.
b. Antenna gain	-	35.4 dB.
c. Frequency	-	2025 to 2120 MHz. Each user at a separate frequency.
d. TDRS signal EIRP	-	43.4 dBw peak normal; 46.0 dBw peak high power.
e. Bandwidth	-	20 MHz narrowband, tunable over 100-MHz band.
f. Duty factor	-	Scheduled as required on a continuous basis.
g. Modulation	-	PN spread spectrum (for chip rate refer to table 1). PSK (±90°), biphase.
h. Desired user I.D.	-	By beam pointing and frequency.

3.4.2.2 Return (Telemetry) Link

a. Antenna	-	3.8-meter diameter parabolic reflector.
b. Antenna gain	-	36 dB.
c. Frequency	-	2200 to 2300 MHz, users separated by frequency.
d. Bandwidth	-	10 MHz.
e. Telemetry data rate	-	Up to 5 Mb/s.
f. Spectrum spreading	-	Not required by TDRSS.
g. Modulation	-	PSK (±90°) biphase (other modulation schemes available because TDRS is a bent pipe and IF outputs from the receiver are available at the ground station).

*See Preface.

3.4.3 KU-BAND SINGLE-ACCESS SYSTEM

3.4.3.1 Forward (Command) Link

a. Antenna	-	3.8-meter* diameter parabolic reflector.
b. Antenna gain	-	52.0 dB.
c. Frequency	-	13.75 to 13.8 GHz.
d. TDRSS signal EIRP		
(1) Normal mode	-	43.0 peak.
(2) High power mode	-	49.0 peak.
e. Bandwidth	-	50 MHz.
f. Duty factor	-	Scheduled as required on a continuous basis.
g. Modulation	-	PN spread spectrun (for chip rate refer to table 1). PSK (±90°), biphase.
h. User selection	-	By beam pointing.

3.4.3.2 Return (Telemetry) Link

a. Antenna	-	3.8-meter* diameter parabolic reflector.
b. Antenna gain	-	52.6 dB.
c. Frequency	-	14.896 to 15.121 GHz.
d. Narrowband mode		
(1) Center frequency	-	14.94 GHz/15.077 GHz (user optional).
(2) Bandwidth	-	88 MHz.
(3) Data rate capability	-	Up to 50 Mb/s biphase.
e. Wideband mode		
(1) Center frequency	-	15.0085 GHz.
(2) Bandwidth	-	225 MHz.
(3) Data rate capability	-	Up to 150 Mb/s (biphase), 300 Mb/s (quadriphase).

*See Preface.

f. Capability - Two narrowband links/TDRS simultaneously or one wideband link/TDRS.

g. Return link configuration - No spectrum spreading required by TDRSS.

h. Modulation - PSK (±90°), biphase (other modulation schemes available because TDRS is a bent pipe and IF outputs are available at the ground station).

i. Tracking - Range and range rate (PN).

Table 1. PN Spread Spectrum Requirements

	Signal EIRP (dBw)	Flux Density Guidelines DBW/M²/4 kHz	Min Spread Bandwidth (MHz)	Required Chip Rate (M Chips/s)*	Duty Factor % Availability of Service
MA S-band	34.0	-154	1.2	.6	100
SA S-band					
Normal Power	43.4	-154	12.0	6.0	100
High Power (Shuttle)	46.0	-154	20.0	10.0	50
SA Ku-band					
Normal Power	43.0	-152	7.0	3.5	100
High Power	49.0	-152	28.0	14.0	25

*Values tentative.

3.5 AVAILABLE DATA ENCODING

The following data coding systems are available on all return links:

a. Forward error control convolutional encoding (R = 2, K = 7), vitberi decoding.

b. NRZM (Δ code).

3.6 S-BAND BEACON

A low power S-band beacon may be available for user autotrack purposes. The frequency of this beacon will be within the multiple-access system band with an earth coverage antenna pattern.

3.7 USER SPACECRAFT TRACKING

3.7.1 GENERAL

The TDRSS will have the capability to obtain user and TDRS tracking data for orbit determination. Error analysis has shown that for orbit maintenance, one TDRS is capable of tracking user spacecraft to the same accuracy as the existing STDN. A comparison of TDRSS with STDN support for launch indicates that, in conjunction with the ground site subnet, launch tracking will be equivalent to existing STDN capabilities. A comparison of the STDN with the TDRSS for long-arc tracking is shown in table 2.

Table 2. TDRSS vs. STDN for Long Data Arcs[1]

User	Position Uncertainty (Meters)	
	STDN	TDRSS[2]
EOS (910 x 910 km, $i=99^o$)	59[3]	58
Shuttle (435 x 435 km, $i=50^o$)	727[3]	703
SAS (560 x 510 km, $i=3^o$)	691[4]	757

1. Assumes 150-meter position uncertainty determined above.
2. Assumes bilateration tracking of TDRS.
3. USB tracking.
4. Minitrack.

3.7.2 MULTIPLE-ACCESS SYSTEM USERS

a. PN range and range rate system.

b. PN spectrum spreading provides forward and return range code.

3.7.3 SINGLE-ACCESS SYSTEM USERS

a. PN range and range rate system.

b. Forward link PN spectrum spreading provides range code.

3.8 OPERATIONAL CHARACTERISTICS

Operationally, the TDRSS subnet is designed to be a real-time, bent-pipe configuration for both telemetry and command data. It will be an integral part of the STDN and will have the following operational characteristics:

a. User Spacecraft Telemetry

(1) Both MA and SA user data will be relayed in real time to a specified destination.

(2) No data storage or any form of processing will be provided by TDRSS as a normal operating procedure.

(3) A 2-hour contingency (only) storage may be provided by NASCOM.

b. User Spacecraft Commands

(1) Real-time throughput from user control centers.

(2) User command verification.

c. User Spacecraft Tracking. PN R&RR data will be sent to orbit determination at GSFC.

d. Scheduling. Scheduling for the TDRSS will be integrated with the ground site subnet scheduling. A single scheduling interface will be presented to the user.

4. ORBITAL COVERAGE CAPABILITIES

4.1 The two-TDRS system will provide the potential for near global real-time coverage (at least 85 percent of each orbit) for most users. This coverage can be provided to all MA users satisfying the assumptions given in para 3.1 and to some high priority SA users which also satisfy these assumptions.

4.2 The zone of exclusion (i.e., area in which coverage cannot be provided) is shown in figure 8 for a vehicle at a 200-kilometer altitude (solid figure) and a 1000-kilometer altitude (dotted figure). For orbital altitudes greater than 1200 kilometers, 100-percent coverage can be provided. The zone of exclusion represents the lower altitude coverage limits for the TDRSS users. The upper altitude coverage limits are 12000 kilometers for the single-access system and 2000 kilometers for the multiple-access system when viewed at the limb from the TDRSS (worst case). In summary, the following coverage is provided:

a. Minimum coverage at 200 kilometers of 85 percent.

b. 100-percent coverage between 1200 and 2000 kilometers (12000 kilometers for single-access).

c. Coverage decreases toward zero for synchronous altitudes.

4.3 The amount of coverage which can be provided to user spacecraft is a function of the users' altitudes and inclinations. Users at low altitudes and low inclinations will pass through the zone of exclusion each orbit and receive the least coverage. Users at high altitudes and high inclinations will pass through the zone of exclusion only periodically, e.g., a user at 1000 kilometers and 99 degrees inclination will pass through the zone of exclusion once per day or less although the duration of this passage will be greater than for a lower inclination mission. The coverage as a function of altitude is summarized in figure 9. This figure, as well as figure 8, refers to the lower limit of coverage previously defined. Coverage charts for some typical user orbital altitudes are contained in appendix B.

5. USER ACQUISITION PROCEDURES

5.1 SINGLE-ACCESS S-BAND USER

Acquisition procedures for a single-access S-band user are as follows:

a. Ground station points TDRS antenna at desired user and uplinks PN coded signal* and antenna pointing commands (where applicable).

b. User acquires PN code, points its antenna (where applicable) and begins transmitting S-band signal.

c. Ground station acquires user S-band signal via TDRS. Ground station uplinks command* to begin transmitting data.

5.2 SINGLE-ACCESS KU-BAND USER

Acquisition procedures for a single-access Ku-band user are as follows:

a. Ground station points TDRS antenna at desired user, uplinks PN coded* S-band signal, and commands user to begin transmitting Ku-band CW beacon.

b. User acquires PN code and begins transmitting Ku-band CW beacon.

*User commands are originated at the user control center; the ground station provides PN coding.

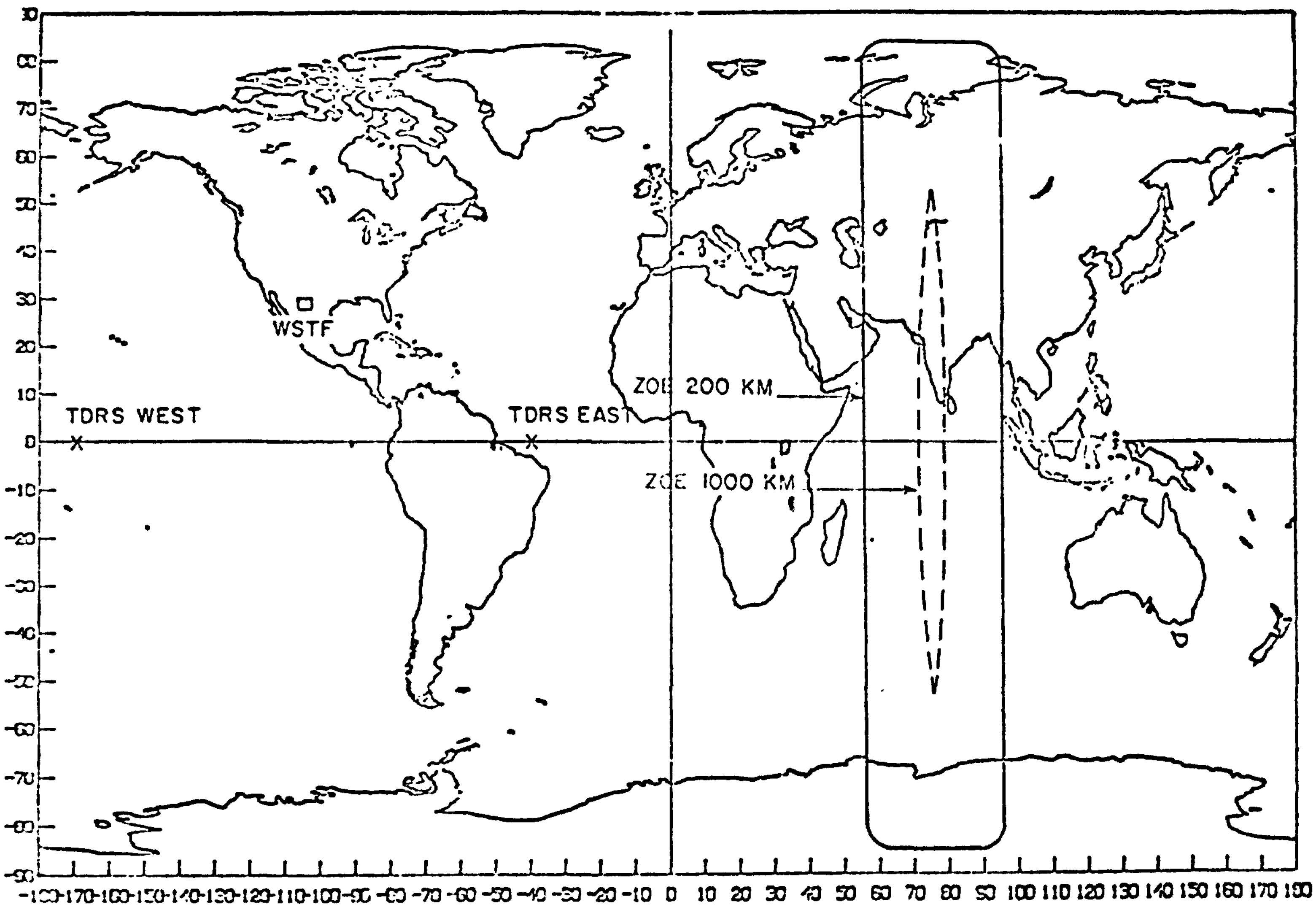


Figure 8. TDRSS Zones of Exclusion

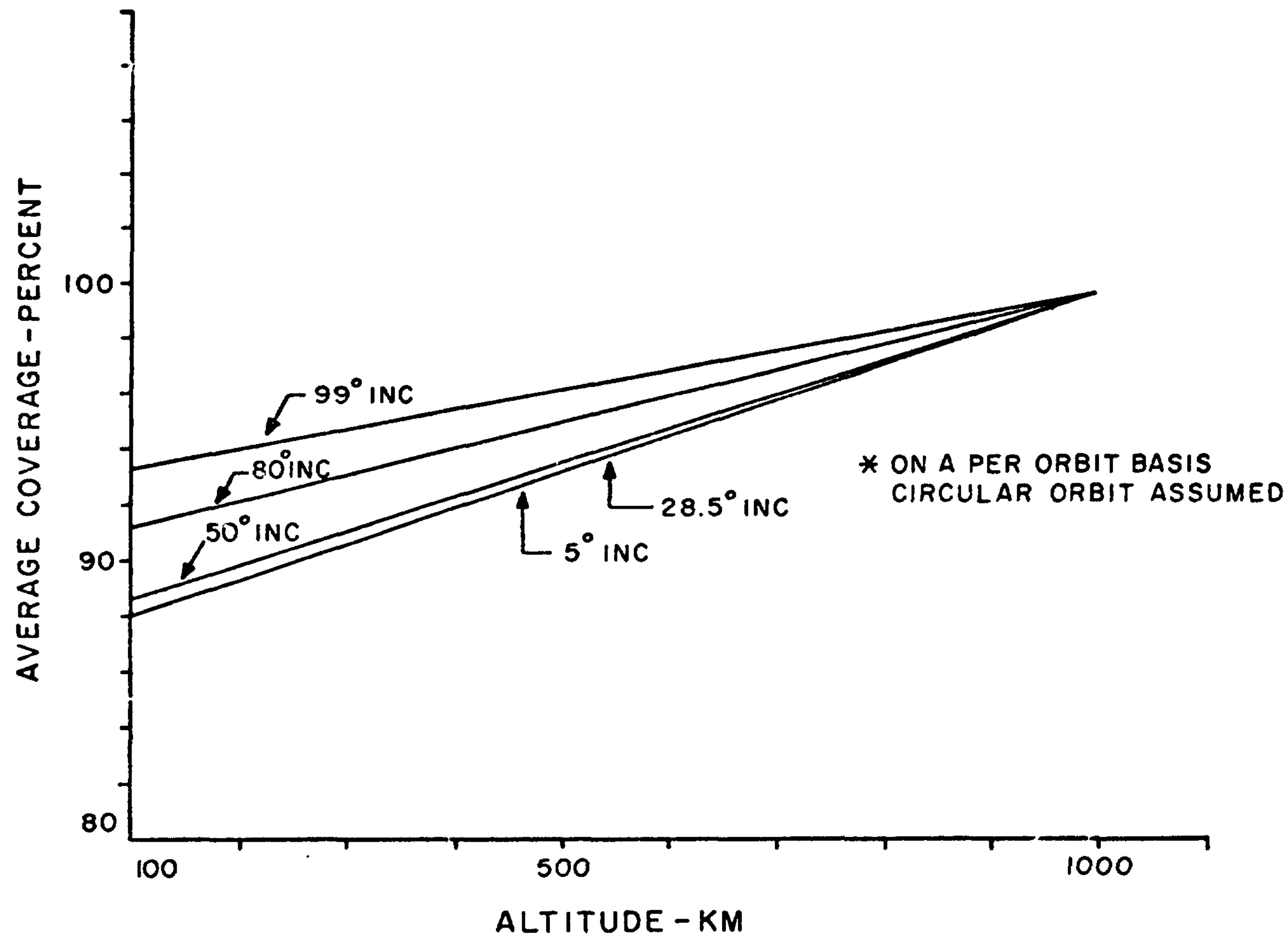


Figure 9. *Average Coverage vs. User Altitude, Various Inclinations

c. Ground station performs search routine with TDRS Ku-band antenna.

d. Ground station acquires user signal, stops search routine, and determines carrier frequency.

e. Ground station sets TDRS VCO to permit TDRS to lock on user CW signal.

f. TDRS autotracks user CW beacon.

g. Ground station uplinks command at S-band to search for TDRS Ku-band CW signal.

h. TDRS transmits 10-dBw EIRP CW signal at Ku-band.

i. User acquires TDRS CW signal and autotracks TDRS.

j. Ground station uplinks command* to begin transmitting data.

5.3 MULTIPLE-ACCESS USERS

Acquisition procedures for multiple-access users are as follows:

a. Ground station points TDRS forward beam and transmits PN coded signal* with user-unique identity code. Ground station configures AGIPA to receive desired user.

b. User acquires PN code, points its antenna (where applicable), and begins transmitting S-band signal (PN coded with user-unique code).

c. Ground station acquires user S-band signal via TDRSS and adjusts return beam "pointing" to maximize signal-to-noise ratio. Ground station uplinks command* to begin transmitting data.

d. Total acquisition time will vary from 5 to 60 seconds, depending on the gain of the user antenna.

6. FLUX DENSITY ANALYSIS, MULTIPLE-ACCESS USER RETURN LINK

6.1 GENERAL

Due to international requirements that the power density of an RF signal impinging on the earth be kept below a specified level, MA users operating with low-gain antennas may not be able to utilize the maximum available coverage period without coordinating their transmissions with ground-based systems. For most potential users, this loss of coverage will not be significant (less than 5 percent of each orbit). However, for a user with an omni antenna in a low earth orbit and with a reasonable data rate, this loss could amount to 20 percent or more of each orbit.

*User commands are originated at the user control center; the ground station adds PN coding.

6.2 POTENTIAL COVERAGE LOSS DUE TO FLUX DENSITY LIMITS

6.2.1 The geometry involved in the analysis problem is shown in figure 10. For each position of the user spacecraft (B), the entire area on the surface of the earth (A) is investigated to determine if the flux density exceeds the specified limits. The angle at which the user is first visible to the TDRS is represented by (α) and (δ) represents the position beyond which the flux density no longer exceeds the limit. The loss in coverage due to excessive flux density is represented by $\alpha - \delta$.

6.2.2 The ground rules and assumptions associated with this analysis are as follows:

a. Independent variables

(1) Telemetry data rate and associated EIRP.

(2) User altitude.

b. Dependent variables

(1) Intermediate - on-axis antenna gain as a function of transmit power to maintain constant EIRP.

(2) User coverage.

c. Constants

(1) Spreading chip rate - 3×10^6 ch/s.

(2) Flux density limits (S-band)

(a) Elevation of user $< 5^\circ$, - 154 dBw/4 kHz/M^2.

(b) Elevation of user $> 5^\circ, < 25^\circ$, $-154 + \frac{\Theta - 5}{2}$, Θ = elevation angle.

(c) Elevation of user $> 25^\circ$, - 144 dBw/4 kHz/M^2.

d. Antenna pattern - omni and greater sin x/x type pattern.

e. Assumption - the user points the maximum of his pattern in the direction of TDRSS.

6.2.3 The coverage loss curves shown in figures 11 and 12 give the potential coverage loss, in percent of an orbit, as a function of user transmitter output power and telemetry bit rate. Because each bit rate curve represents a constant EIRP, as transmitter power increases antenna gain decreases.

6.2.4 As a result of the analysis, it is recommended that a user attempt to maximize his antenna gain and minimize the transmitter power output to minimize his coverage loss.

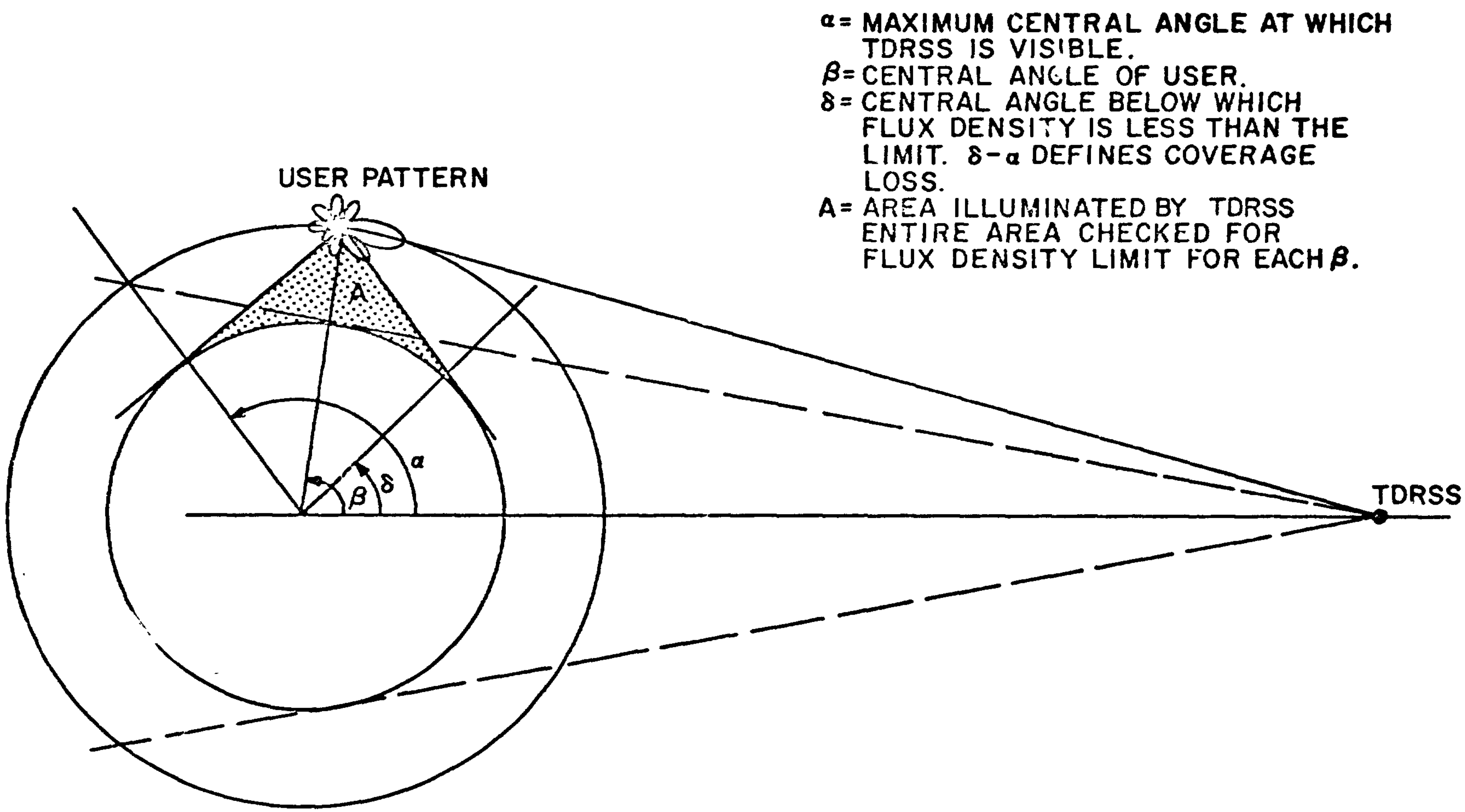


Figure 10. Geometry for Potential Coverage Loss due to Flux Density Limits

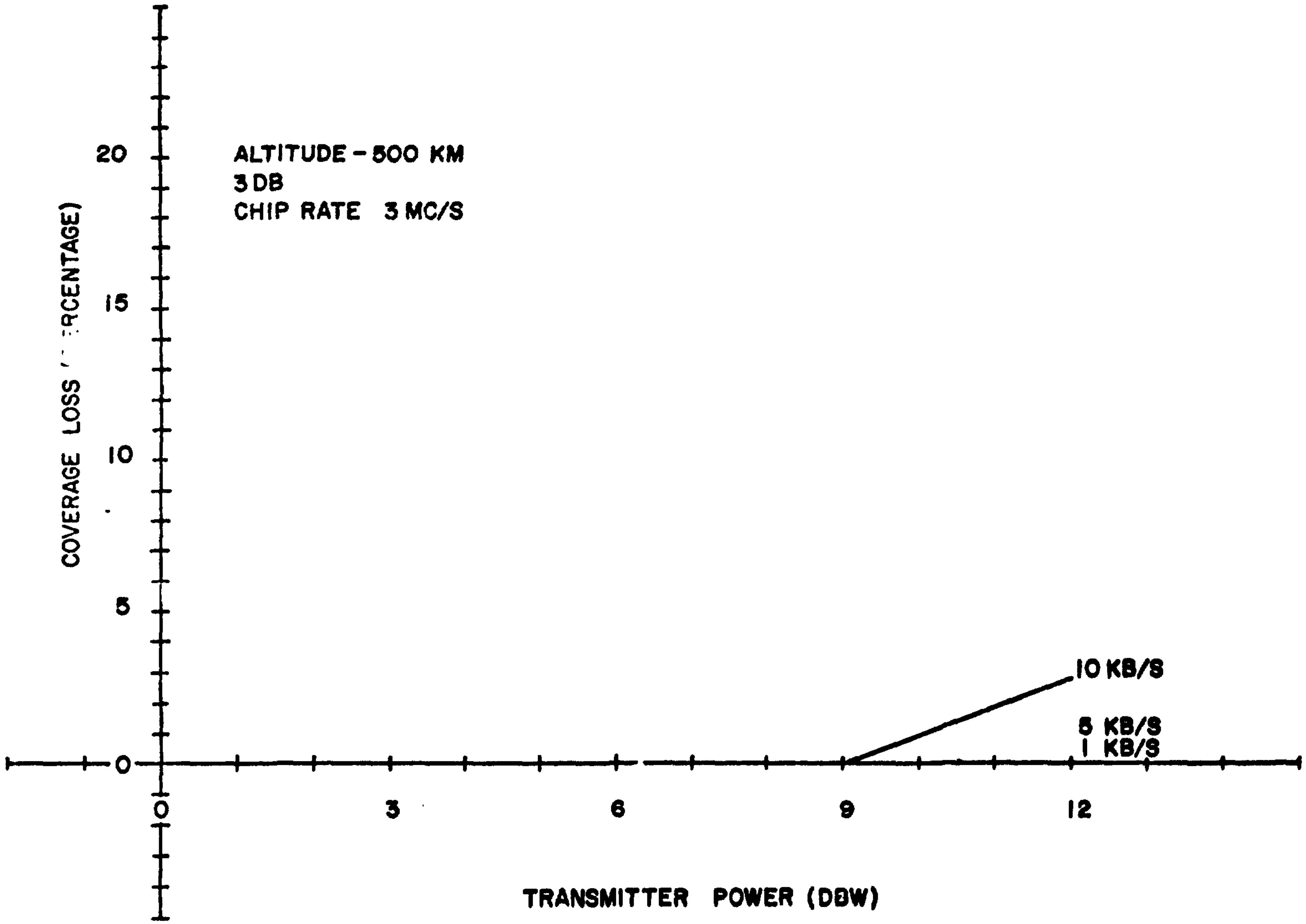


Figure 11. Coverage Loss vs. Transmitter Power (500 km Altitude)

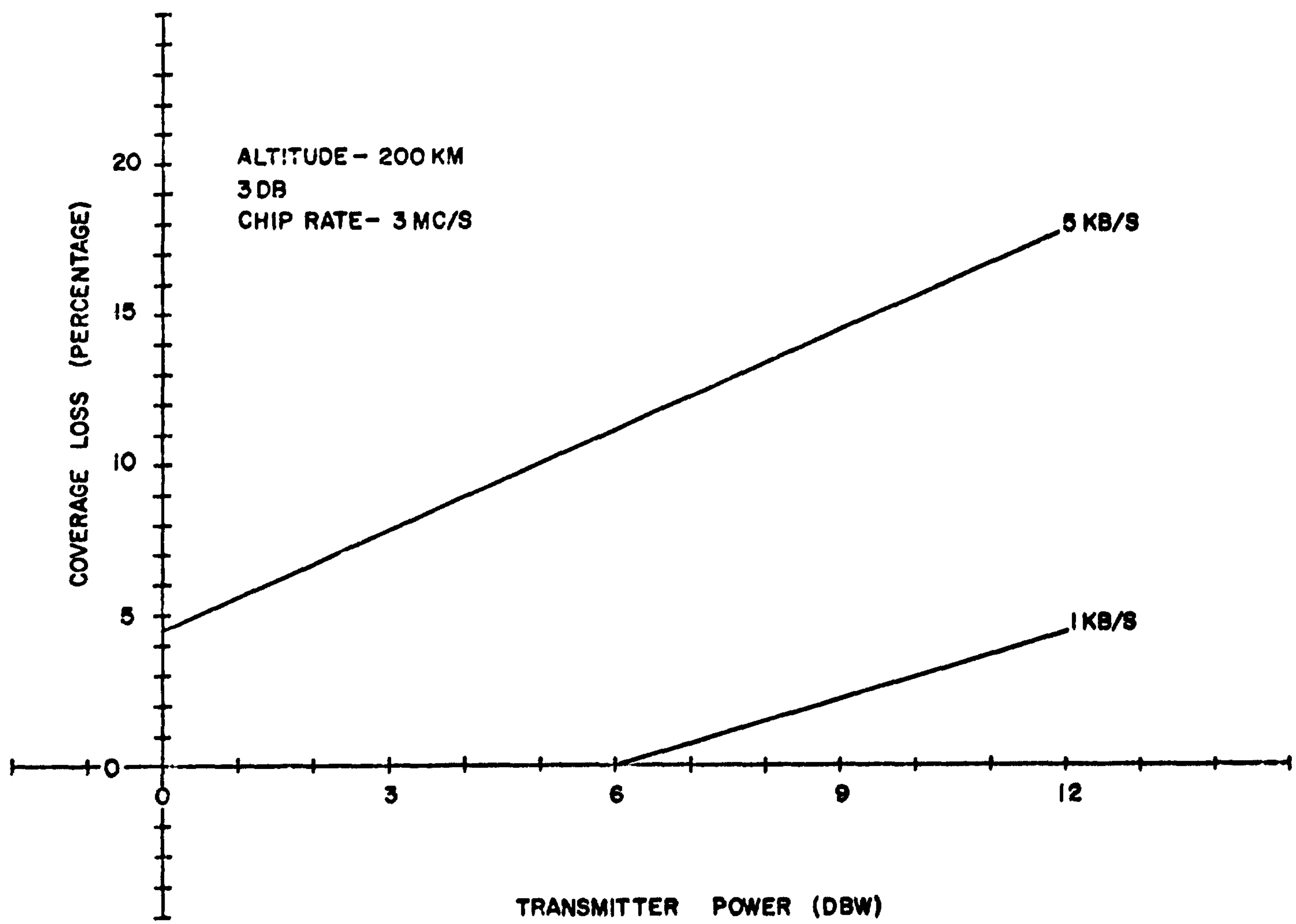


Figure 12. Coverage Loss vs. Transmitter Power (200 km Altitude)

7. USER SPACECRAFT COMPATIBILITY

7.1 GENERAL

In general, operation with TDRSS will have an impact on the user, either single or multiple access, due to the longer transmission ranges involved. These impacts are discussed in the following paragraphs and do not consider potential compensating advantages to the use of TDRSS such as the possible deletion of tape recorders or the value of real-time data and real-time access. For purposes of discussion, a typical user receiving support from the ground based STDN is assumed to have the following charactertistics:

a. An S-band transmitter receiver pair or an S-band transponder.

Note

VHF support is currently scheduled for deletion from the STDN by January 1, 1980.

b. A low gain, earth pointed S-band antenna.

c. Sufficient EIRP and receive g/t for operation with a 9-meter ground-based system.

d. A tape recorder sufficient to store one full orbit of data.

7.2 RECEIVE SYSTEM IMPACTS

7.2.1 MULTIPLE-ACCESS USERS

The impacts on the multiple-access users' receive systems are as follows:

a. Addition of a spread spectrum receiver with PN correlator and phase lock loop.

b. Digital command decoder.*

c. Receive antenna gains in the -5 dB to +4 dB range (100 - 1000 b/s command rates).

7.2.2 SINGLE-ACCESS USERS

The impacts on the single-access users' receive systems are as follows:

a. Addition of a spread spectrum receiver with PN correlator and phase lock loop.

b. Digital command decoder.*

c. Receive antenna gains in the 0 dB to +10 dB range (1000 - 10000 b/s at S-band). Ku-band SA users will also require a gainful antenna (see appendix A).

d Most users will also require a low gain (omni) for contingency command.

*This item will not represent any additional impact on some users.

7.3 TRANSMISSION SYSTEM IMPACTS

7.3.1 MULTIPLE-ACCESS USERS

The impacts on the multiple-access users' transmission systems are as follows:

a. Addition of a spread spectrum transmitter which may be part of a spread spectrum transponder if coherent ranging is desired.

b. Additional dc power for transmitter if continuous real-time operation is required.

c. Increased EIRP which may generally be satisfied with a directional antenna and possibly some increase in transmitter power. In some cases switchable fixed antenna elements will be sufficient while others may require steerable antennas.

d. Digital telemetry system.*

7.3.2 SINGLE-ACCESS USERS

The impacts on the single-access users' transmission systems are as follows:

a. Use of a coherent transponder if coherent tracking is required.* Spread spectrum is not required by TDRSS; however it may be required to comply with CCIR regulations.

b. Additional dc power for transmitter if increased coverage is desired.

c. Increased EIRP which may generally be satisfied with directional antennas and possibly some increase in transmitter power. Single-access users will normally require steerable antennas such as yagi's, helices, or parabolas depending on their data rate requirements.

*This item will not represent any additional impact for some users.

APPENDIX A. TDRSS/USER LINK CALCULATIONS

1. GENERAL

This appendix contains the TDRSS/user link calculations. The calculations, which are based on state-of-the-art communications terminals on the user spacecraft, show available telemetry or command data rates (without spectrum spreading) as a function of user antenna gain (forward link) or user EIRP (return link). The links are based on achieving the indicated Bit Error Rate (BER) for the available data rate, and assume the worst-case channel characteristics. Each calculation contains a 3-dB margin. Tables A-1 through A-6 contain the calculations for each link, while figures A-1 through A-6 graphically illustrate each calculation.

2. PARAMETER DEFINITIONS

2.1 FORWARD LINKS

The following parameters are used in the calculations for the forward links (not all parameters are included in each calculation):

a. BER - Bit Error Rate

b. TDRSS Antenna Gain - For multiple-access, the gain at field of view edge ±13° off local NADIR; for single-access, the on-axis gain.

c. TDRSS Transmit Power - Power out of the TDRSS transmitter.

d. RF Transmit Losses - TDRSS RF losses between the transmitter and the antenna.

e. Transmitter EIRP (dBw) Peak (S+N) - Actual maximum transmitted EIRP from TDRSS.

f. TDRS Transponder Loss - Tandem link loss in TDRS transponder.

g. Peak Signal EIRP - Transmitted EIRP less transponder loss.

h. Antenna Pointing Losses - Losses resulting from antenna pointing inaccuracy.

i. Signal EIRP - Usable signal transmitted in the direction of the user.

j. EIRP - Effective Isotropic Radiated Power of TDRS.

k. Space Loss	-	Space loss on TDRS/user link.
l. User Antenna Gain	-	Gain of user antenna in direction of TDRS.
m. Polarization Loss	-	Losses resulting from misalignment of polarization vector between TDRS and user.
n. P_s out of User Antenna	-	RF power at output terminal of user antenna.
o. T_s	-	Noise temperature at output terminal of user antenna (includes line losses).
p. KT_s	-	Noise power at output terminal of user antenna.
q. P_s/KT_s	-	Signal-to-noise ratio at output of user antenna.
r. Demodulation/Bit Sync Loss	-	Degradation of BER in digital demodulator/bit synchronizer on user spacecraft.
s. Modulation Loss	-	Degradation caused by correlation process on user spacecraft.
t. Residual Carrier Loss	-	Modulation loss.
u. System Margin	-	System operating margin.
v. Required E_b/N_o	-	Bit signal-to-noise ratio required to achieve the given BER.
w. Forward Error Control (FEC) Gain	-	FEC coding gain.

2.2 RETURN LINKS

The following parameters are used in the calculations for the return links:

a. BER	-	Bit Error Rate
b. User EIRP	-	Effective isotropic radiated power of user spacecraft.
c. Space Loss	-	Space loss on TDRS/user link.
d. Pointing Loss	-	Losses resulting from antenna pointing inaccuracy.
e. Polarization Losses	-	Losses resulting from misalignment of polarization vector between TDRS and user.

f. TDRS Antenna Gain - For multiple-access, the gain at the FOV edge $\pm 13^{o}$ off axis; for single-access, the on-axis gain.

g. P_s at Output of Antenna - RF power at terminals of TDRS antenna.

h. T_i - Equivalent noise temperature at output of TDRS antenna due to presence of other user signals.

i. T_s - Noise temperature at terminal of TDRS antenna, including line losses (thermal noise). The T_s calculation in the single-access return link (Ku-band) is:

$$T_s = 253 + 290\ (0.67) + T_e\ (1.6) + T_{e2}\ (1.6)\ (0.03)$$

$$= 253 + 193 + 240 + 24$$

$$= 710^{o}$$ (445^{o} at input to preamp, assumed line loss of 2 dB)

(T_e = preamp temp T_{e2}=temp of following stage.)

The T_s calculation for the S-band return links is:

$$T_s = 234 + 290\ (0.6) + T_e\ (1.6) + T_{e2}\ (1.6)\ (0.03)$$

$$= 234 + 174 + 400 + 16.8$$

$$= 824^{o}$$ (520^{o} at input of preamplifier, assumed line loss of 2 dB)

j. $K(T_s+T_i)$ - Total noise power (all sources) at output of TDRS antenna.

k Transponder Loss - Multiplexing, demultiplexing, and tandem link loss on TDRS.

l. Demodulation Loss - Degradation of BER in digital demodulator/bit synchronizer at TDRSS ground terminal.

m. PN Loss - Degradation caused by correlation process at TDRSS ground terminal.

n. Residual Carrier Loss - Modulation loss.

o. AGIPA Loss - Applies to the multiple-access system only, loss in AGIPA processor.

p. System Margin - System operating margin.

q. Required E_b/N_o - Bit signal-to-noise ratio required to achieve the given BER.

r. FEC Gain - FEC coding gain.

Table A-1. Calculation for Multiple-access Forward Link, S-band

BER	10^{-5}
TDRS Antenna Gain (dB)	23.0
TDRS Transmit Power (dBw)	13.0
RF Transmit Loss (dB)	-1.0
Transmitted EIRP (dBw) Peak (S+N)	35.0
TDRS Transponder Loss (db)	-1.0
Peak Signal EIRP (dBw)	34.0
Antenna Pointing Loss (dB)	0.0
Signal EIRP (dBw)	34.0
Space Loss (db)	-191.6
User Antenna Gain (dB)	G_u
Polarization Loss (dB)	-0.5
P_s - Signal Power Out of User (dBw)	$-158.1 + G_u$
T_s (Antenna Output) (^oK)	824
T_s (dB)	29.2
KT_s (dBw/Hz)	-199.4
P_s/KT_s (dB-Hz)	$41.3 + G_u$
Demodulation/Bit Sync Loss (dB)	-1.5
Demodulation Loss (PN) (dB)	-1.0
Residual Carrier Loss (dB)	0.0
Required E_b/N_o (dB-Hz) (Δ PSK)	-9.9
System Margin (dB)	-3.0
Achievable Data Rate (dB)	$25.9 + G_u$
Theoretical FEC Gain R=2, K=7 (dB)	5.2
Achievable Data Rate (dB)	$31.1 + G_u$

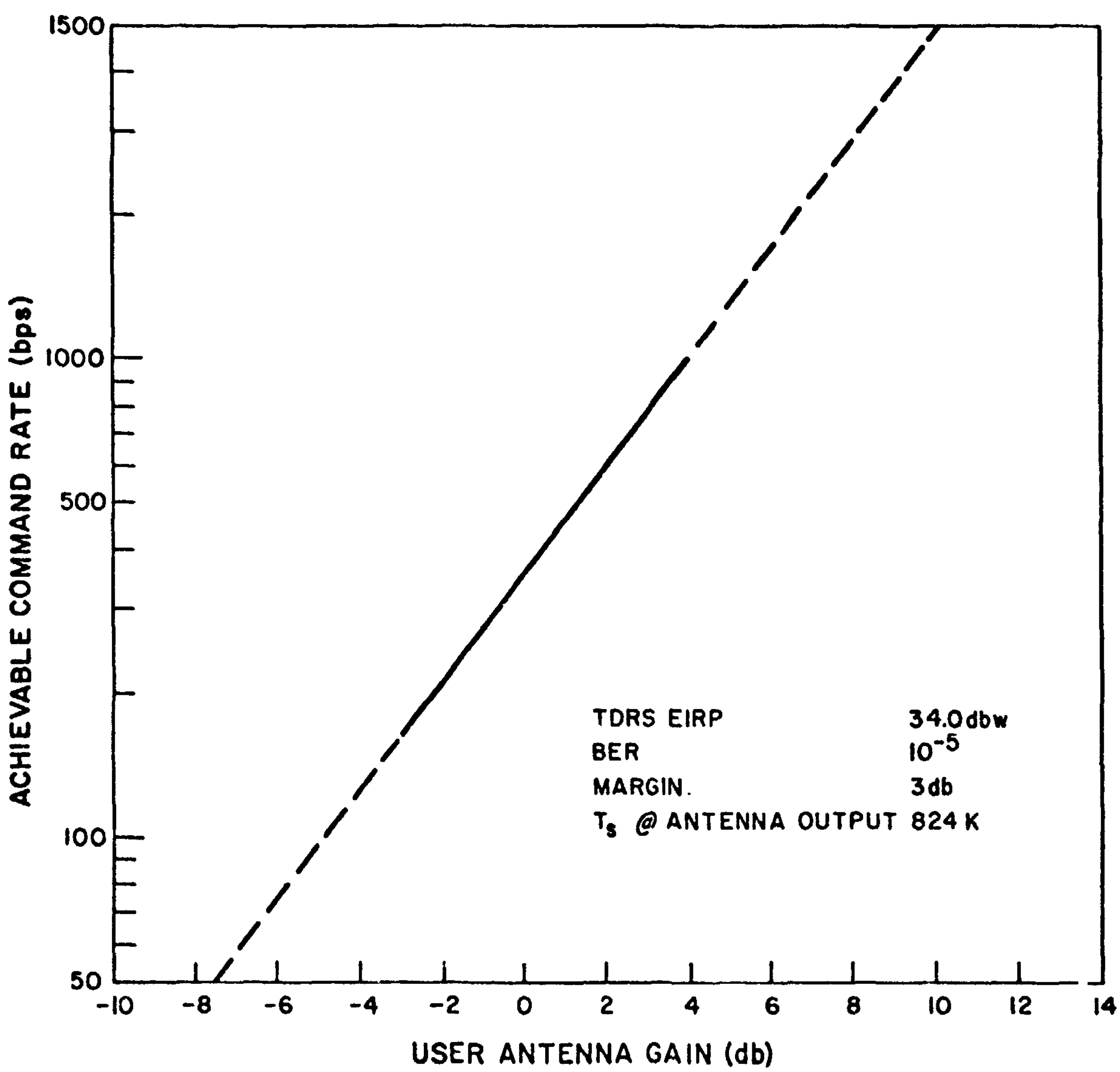


Figure A-1. Multiple-access Forward Link (S-band), Achievable Command Rate vs. User Antenna Gain

Table A-2. Calculation for Single-access Forward Link, S-band

BER	10^{-5}
TDRS Antenna Gain (dB)	35.4
TDRS Transmit Power (dBw)	11.5
RF Transmit Loss (dB)	-2.0
Transmitted EIRP (dBw) Peak (S+N)	44.9
TDRS Transponder Loss (dB)	-1.0
Peak Signal EIRP (dBw)	43.9
Antenna Pointing Loss (dB)	-0.5
Signal EIRP (dBw)	43.4*
Space Loss (dB)	-191.6
User Antenna Gain (dB)	G_u
Polarization Loss (dB)	-0.5
P_S - Signal Power Out of User (dBw)	-148.7 + G_u
T_s (Antenna Output) (^oK)	824
T_s (dB)	29.2
KT_s (dBw/Hz)	-199.4
P_s/KT_s (dB-Hz)	50.7 + G_u
Demod/Bit Sync Loss (dB)	-1.5
Modulation Loss (PN) (dB)	-1.0
Residual Carrier Loss (dB)	0.0
Required E_b/N_o (dB-Hz) (Δ PSK)	-9.9
System Margin (dB)	-3.0
Achievable Data Rate (dB)	35.3 + G_u
Theoretical FEC Gain R=2, K=7 (dB)	5.2
Achievable Data Rate (dB)	40.5 + G_u

*An additional 2.6- dB EIRP is available as a high power mode on a 50-percent duty cycle.

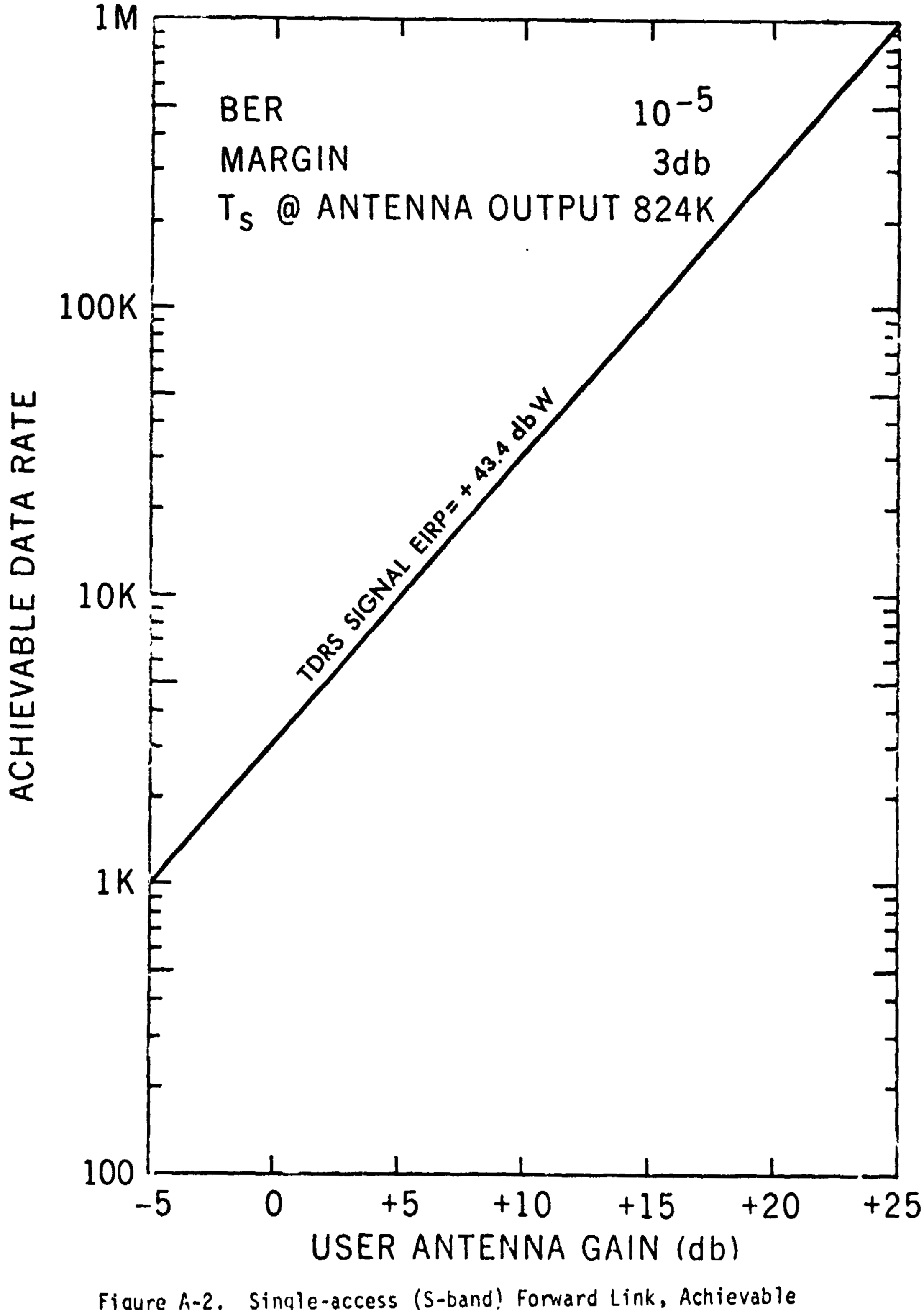


Figure A-2. Single-access (S-band) Forward Link, Achievable Data Rate vs. User Antenna Gain

Table A-3. Calculation for Single-access Forward Link, Ku-band

BER	10^{-5}
TDRS Antenna Gain (dB)	52.0
TDRSS Transmit Power (dBw)	-5.5
RF Transmit Loss (dB)	-2.0
Transmitted EIRP (dBw) Peak (S+N)	44.5
TDRS Transponder Loss (dB)	-1.0
Peak Signal EIRP (dBw)	43.5
Antenna Pointing Loss (dB)	-0.5
Signal EIRP (dBw)	43.0*
Space Loss (dB)	-208.6
User Antenna Gain (dB)	G_u
Polarization Loss (dB)	-0.5
P_s - Signal Power Out of User (dBw)	-166.1 + G_u
T_s (Antenna Output) (°K)	710
T_s (dB)	28.5
KT_s (dBw/Hz)	-200.1
P_s/KT_s (dB-Hz)	34.0 + G_u
Demod/Bit Sync Loss (dB)	-1.5
Modulation Loss (PN) (dB)	-1.0
Residual Carrier Loss (dB)	-1.0
Required E_b/N_o (dB-Hz) (Δ PSK)	-9.9
System Margin (dB)	-3.0
Achievable Data Rate (dB)	17.6 + G_u
Theoretical FEC Gain R=2, K=7 (dB)	5.2
Achievable Data Rate (dB)	22.8 + G_u

*An additional 6-dB EIRP is available as a high power mode on a 25-percent duty cycle.

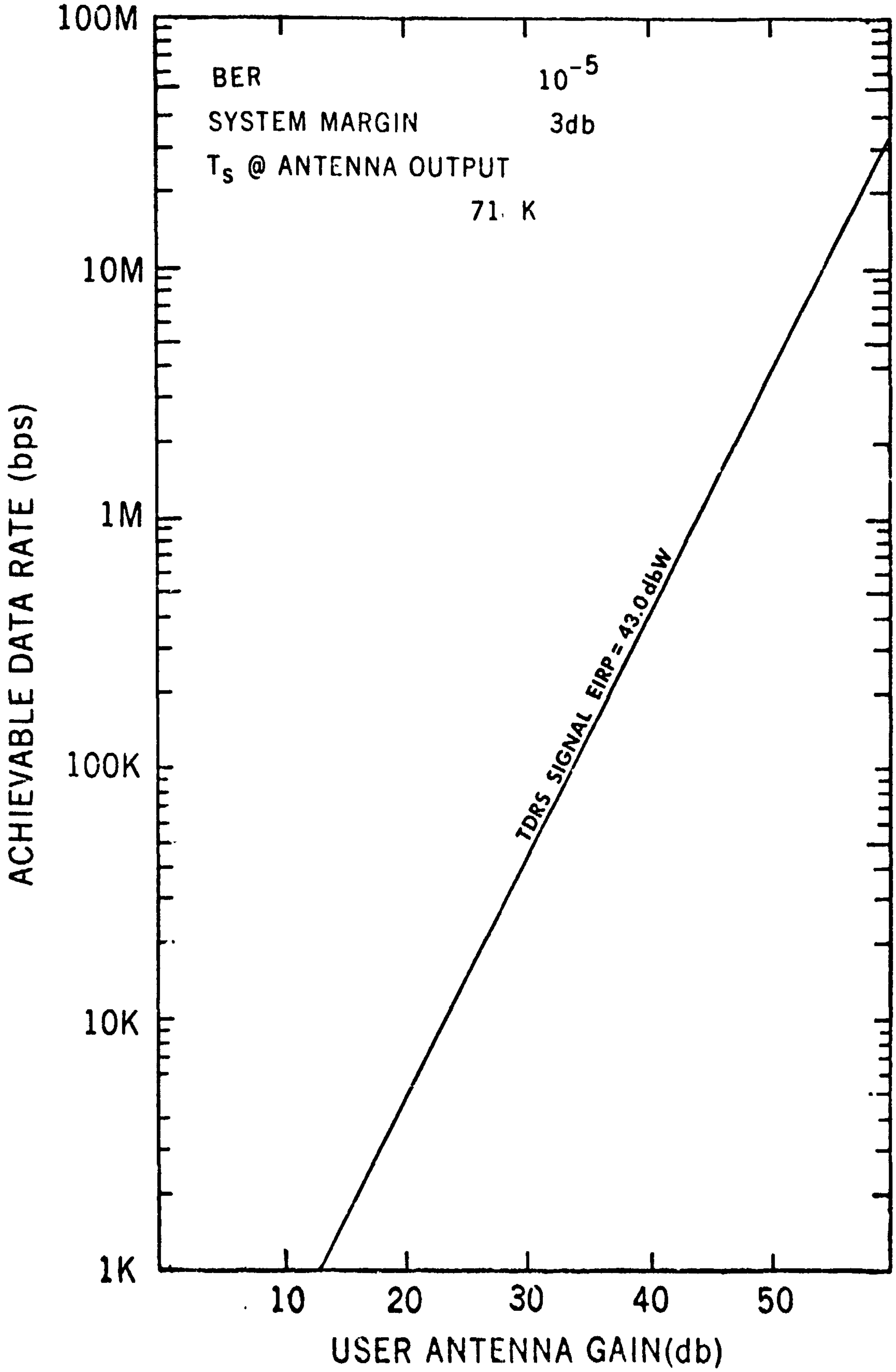


Figure A-3. Single-access (Ku-band) Forw.~rd Link, Achicvable Data Rate vs. User Antenna Gain

Table A-4. Calculation for Multiple-access Return Link, S-band

BER	10^{-5}
User EIRP (dBW)	EIRP
Space Loss (dB)	-192.2
Polarization Loss (dB)	-1.0
TDRS Antenna Gain @ ±13° (dB)	28.0
P_s at Output of Antenna (dBW)	-165.2 + EIRP
T_i (antenna output terminals) (°K)	824
T (due to direct other user interference)	255
$K(T_s + T_i)$ (dBW)	-198.3
$P_s/K(T_s + T_i)$	+33.1 + EIRP
Transponder Loss (dB)	-2.0
Demodulation Loss (dB)	-1.5
PN Loss (dB)	-1.0
AGIPA Loss (dB)	-0.5
System Margin (dB)	-3.0
Required E_b/N_o (10^{-5} BER), ΔPSK	-9.9
Achievable Data Rate (dB)	+15.2 + EIRP
FEC Gain, R = 2, K = 7 (dB)	5.2
Achievable Data Rate (dB)	+20.4 + EIRP

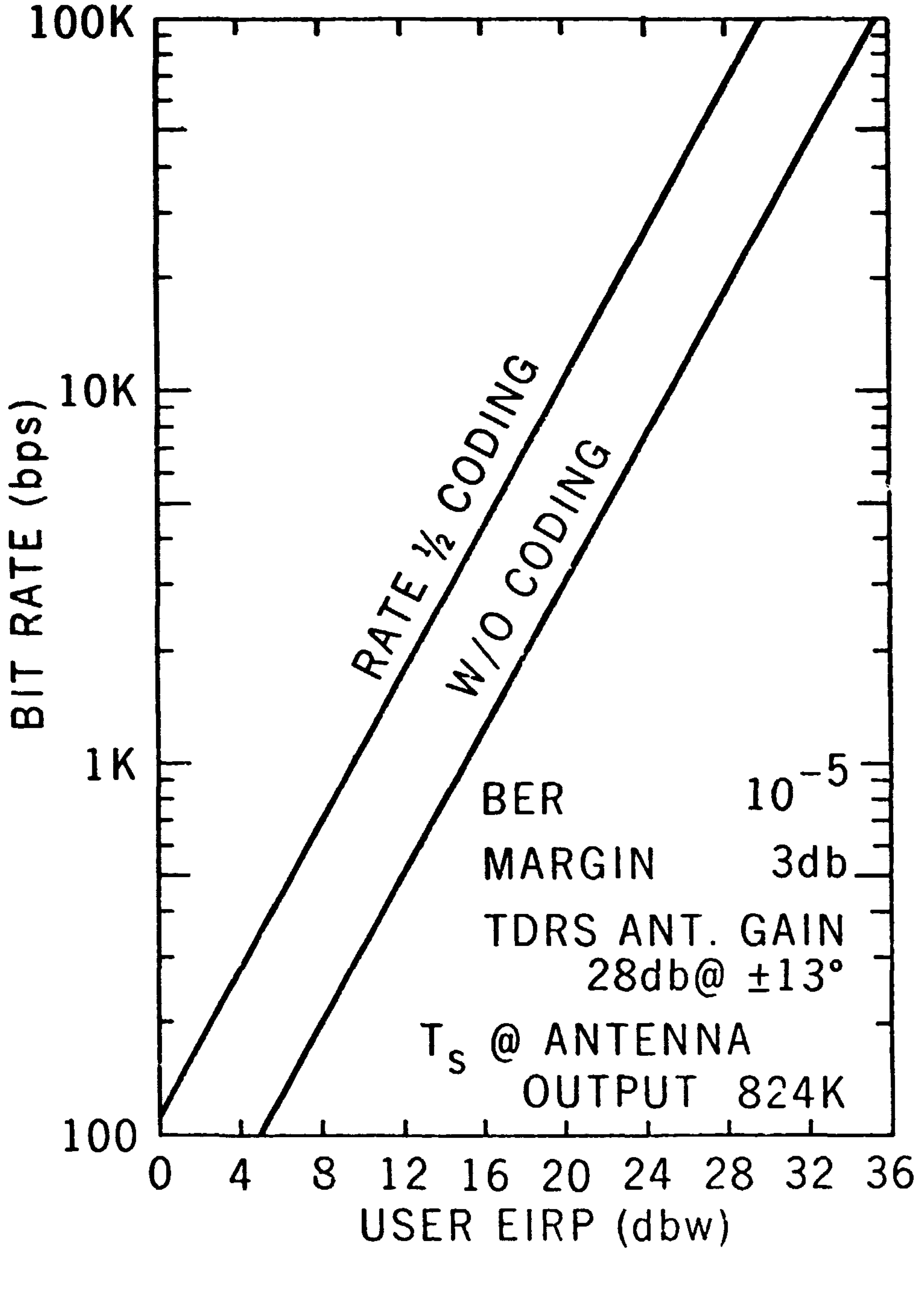


Figure A-4. Multiple-access (S-band) Return Link,
Data Rate vs. User EIRP

Table A-5. Calcul ion for Single-access Return Link, S-band *

BER	10^{-5}
User EIRP	EIRP
Space Loss (dB)	-192.2
Pointing Loss (dB)	-0.5
Pol. Loss (dB)	-0.5
TDRS Antenna Gain (dB)	36.0 (50%)**
P_s at Output of Antenna (dBW)	-157.2 + EIRP
T_i (because of direct other user interference) (°K)	----
T_s (Antenna Output Terminals) (°K)	824
KT_s at Output of Antenna	-199.4
P_s/KT_s	42.2 + EIRP
Transponder Loss (dB)	-2.0
Demodulation Loss (dB)	-1.5
PN Loss (dB)	0.0
Residual Carrier Loss (dB)	0
AGIPA Loss (dB)	
System Margin (dB)	-3.0
Required E_b/N_0, ΔPSK	-9.9
Achievable Data Rate (dB)	25.8 + EIRP
FEC Gain, R = 2, K = 7 (dB)	5.2
Achievable Data Rate (dB)	31.0 + EIRP

*These link parameters are under continuing optimization and definition.

**On axis.

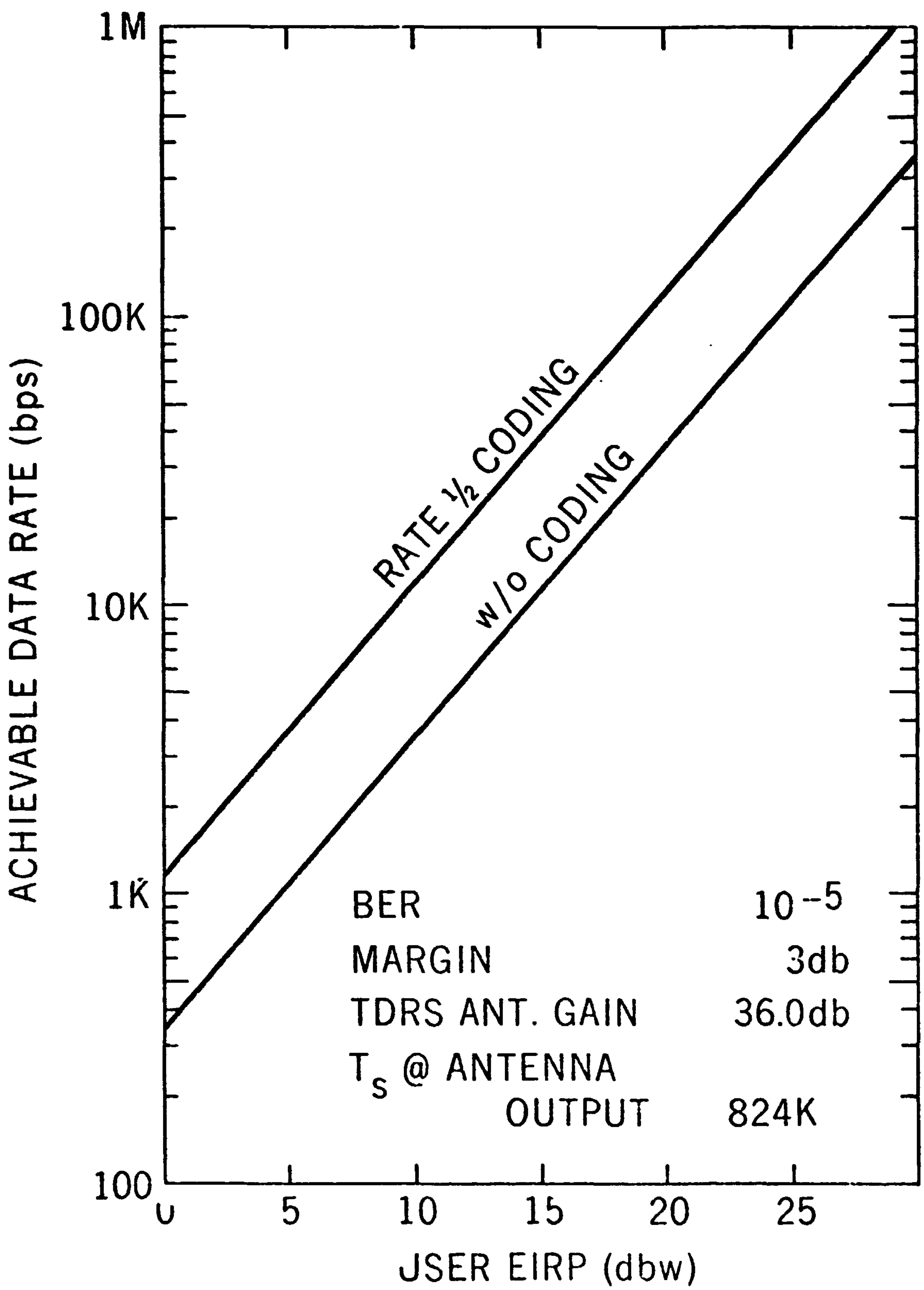


Figure A-5. Single-access (S-band) Return Link, Achievable Data Rate vs. User EIRP (See Note on Table A-5)

Table A-6. Calculation for Single-access Return Link, Ku-band

BER	10^{-5}
User EIRP (dBW)	EIRP
Space Loss (dB)	-209.2
Pointing Loss (dB)	-0.5
Pol. Loss (dB)	-0.5
TDRS Antenna Gain (dB)	52.6 (55%)*
P_s at Output of Antenna (dBW)	-157.6 + EIRP
T_i (because of direct other user interference)	----
T_s (Antenna Output Terminals) (^oK)	710
KT_s at Output of Antenna	-200.1
P_s/KT_s	42.5 + EIRP
Transponder Loss (dB)	-2.0
Demodulation Loss (dB)	-1.5
PN Loss (dB)	0
Residual Carrier Loss (dB)	-1.0
AGIPA Loss (dB)	
System Margin (dB)	-3.0
Required E_b/N_o, Δ PSK	-9.9
Achievable Data Rate (dB)	25.1 + EIRP
FEC Gain, R = 2, K = 7 (dB)	5.2
Achievable Data Rate (dB)	30.3 + EIRP

*On axis.

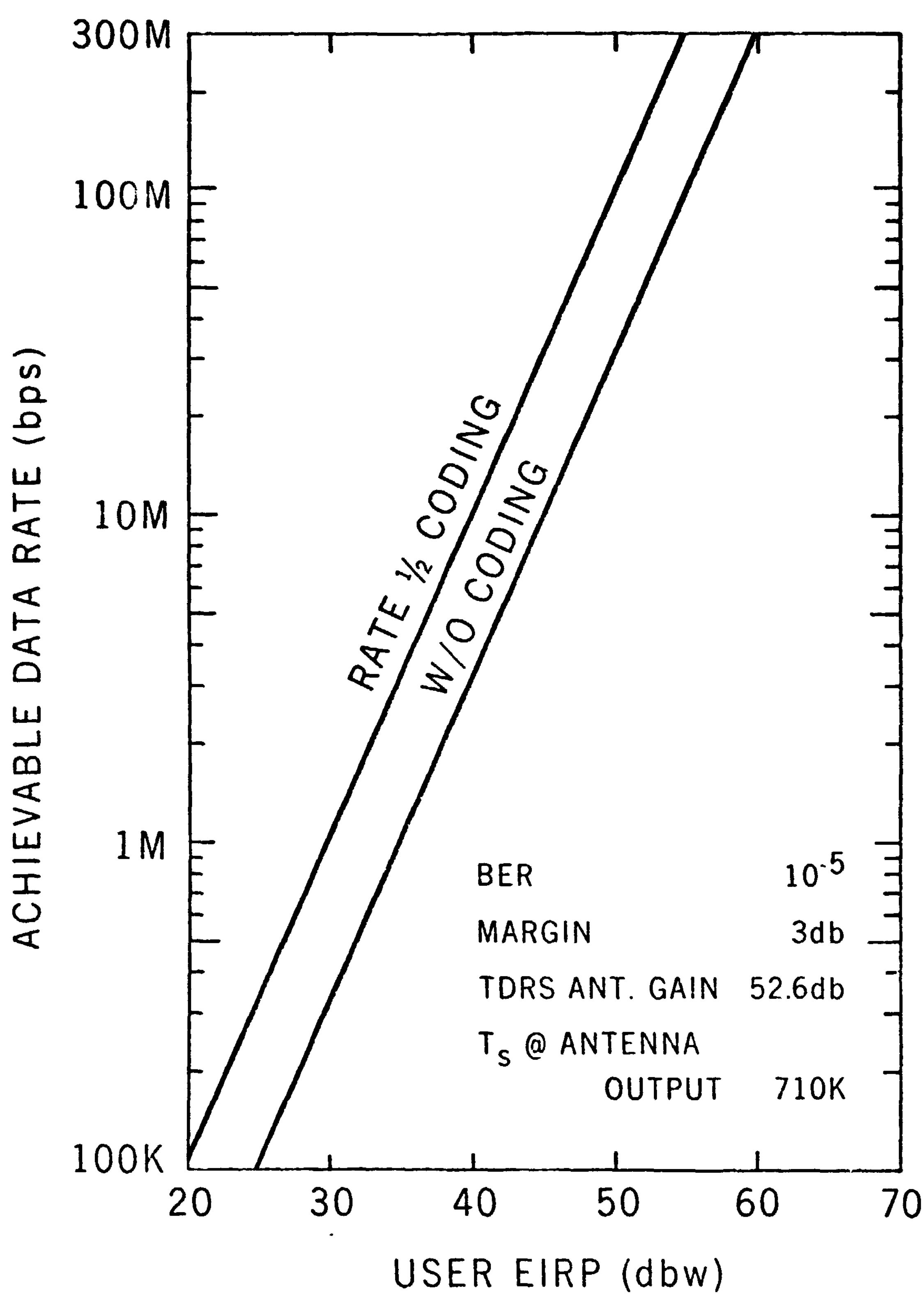


Figure A-6. Single-access (Ku-band) Return Link, Achievable Data Rate vs. User EIRP

APPENDIX B. COMBINED TDRSS AND GROUND STDN SITE COVERAGE

1.1 Figures B-1 through B-18 show STDN coverage as a function of user altitude, from 200 km to 30,000 km. (shaded areas indicate no coverage) Figures B-1 through B-6 show the lower coverage zone (200 km to 1200 km); figures B-7 through B-9 show the mid coverage zone (1200 km to 12000 km), and figures B-10 through B-18 show the upper coverage zone (12,000 km and up). All figures are based on geometrical considerations, not simulations.

1.2 All figures assume that the TDR satellites are spaced 130 degrees apart and in synchronous altitudes. TDRS east is placed at 0 degrees latitude and 171 degrees west longitude while TDRS west is placed at 0 degrees latitude and 41 degrees west longitude. The maximum TDRS single-access antenna steering angle assumed is 62 degrees north and south and 45 degrees east and west. The coverage area shown for the satellites is the maximum available coverage at the indicated altitudes, whereas the ground station coverage areas show only that coverage above a 5-degree elevation angle (masking not included). Ground station coverage is provided by Goldstone, Alaska, Madrid, Orroral, Rosman, Merritt Island, and Tananarive (launch only).

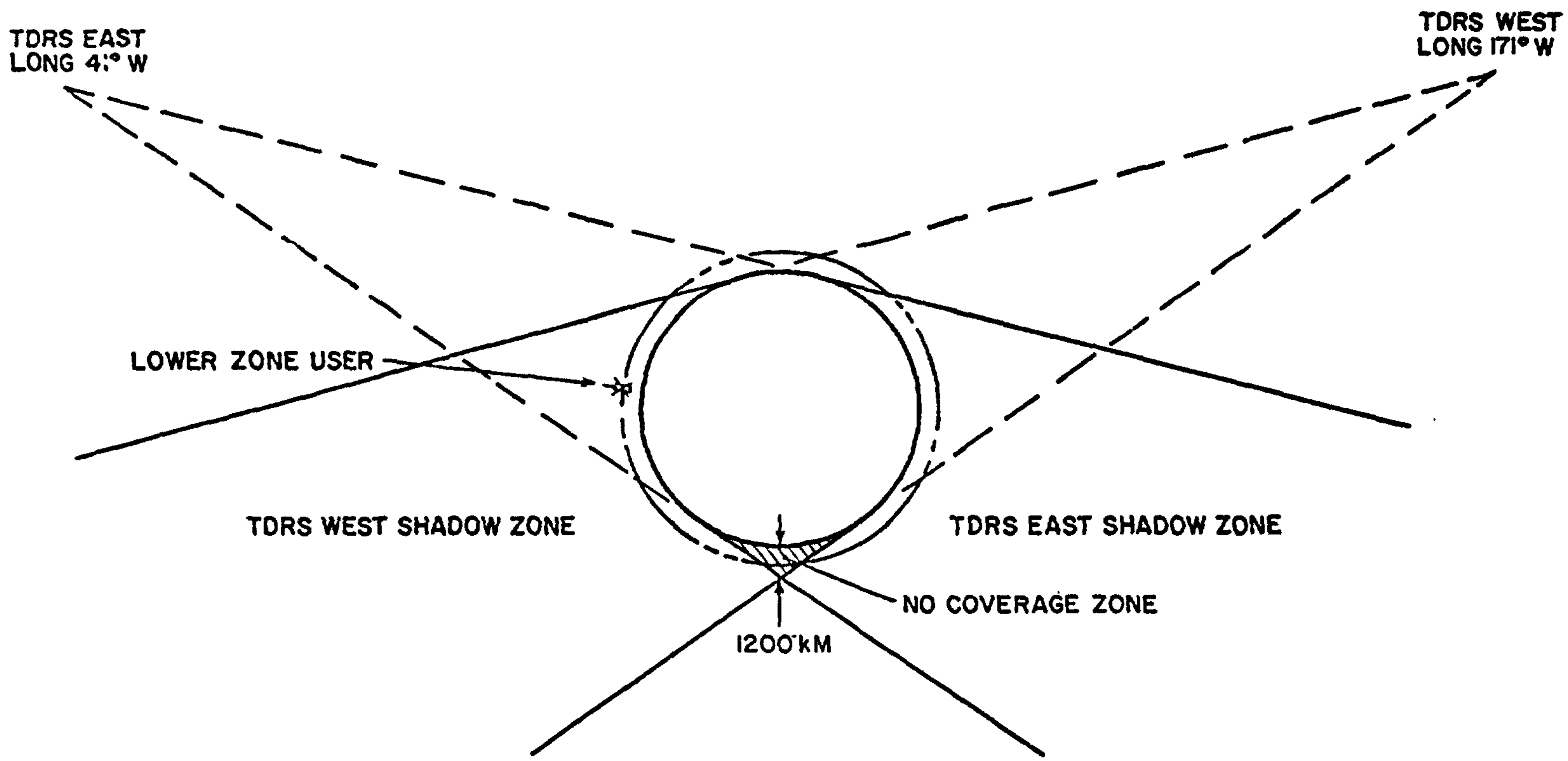


Figure B-1. Lower Coverage Zone Geometry (Altitude Less Than 1200 km)

The following chart defines the symbols and coverage zone notation used in the lower coverage zone charts.

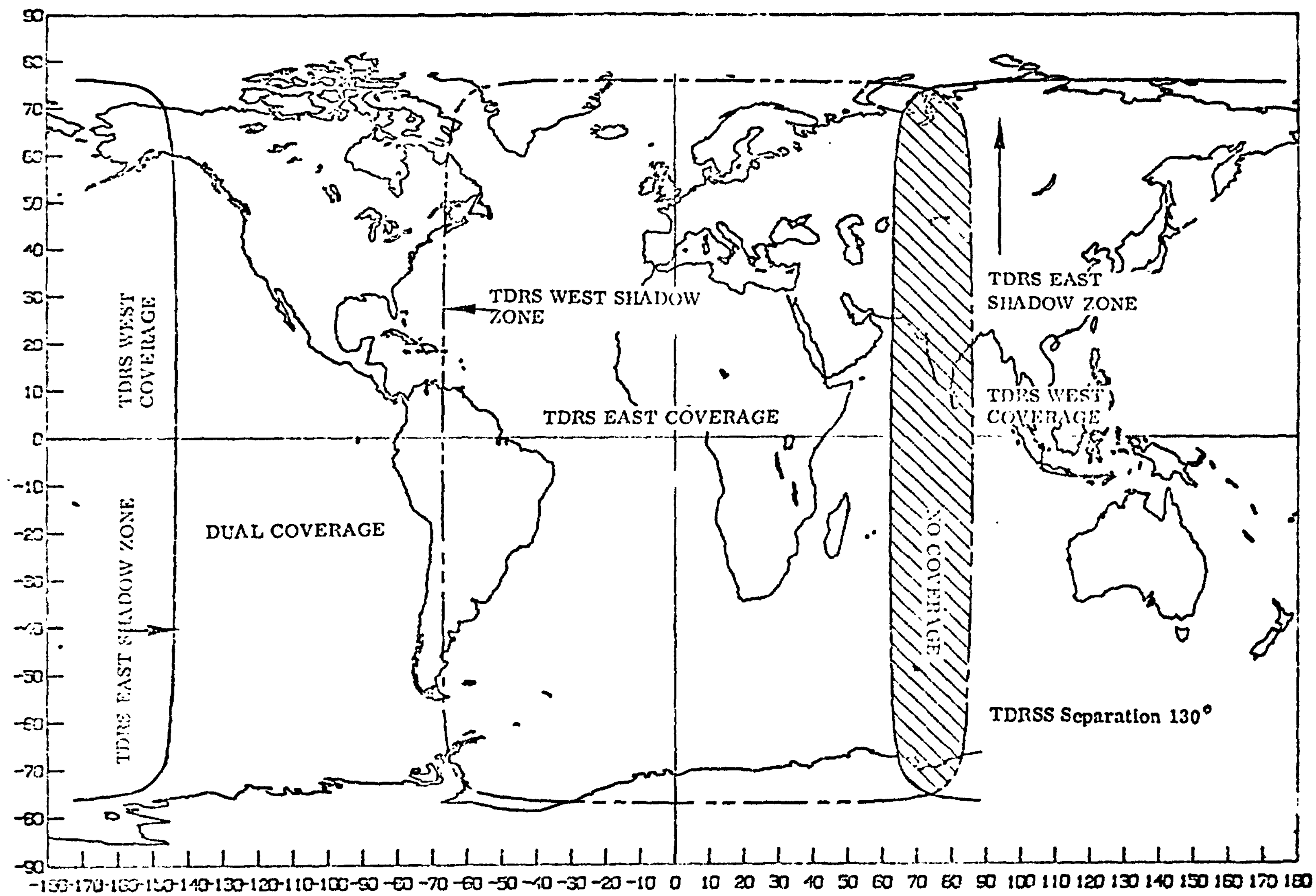


Figure B-2. TDRSS Lower Coverage Zone, TDRSS Only

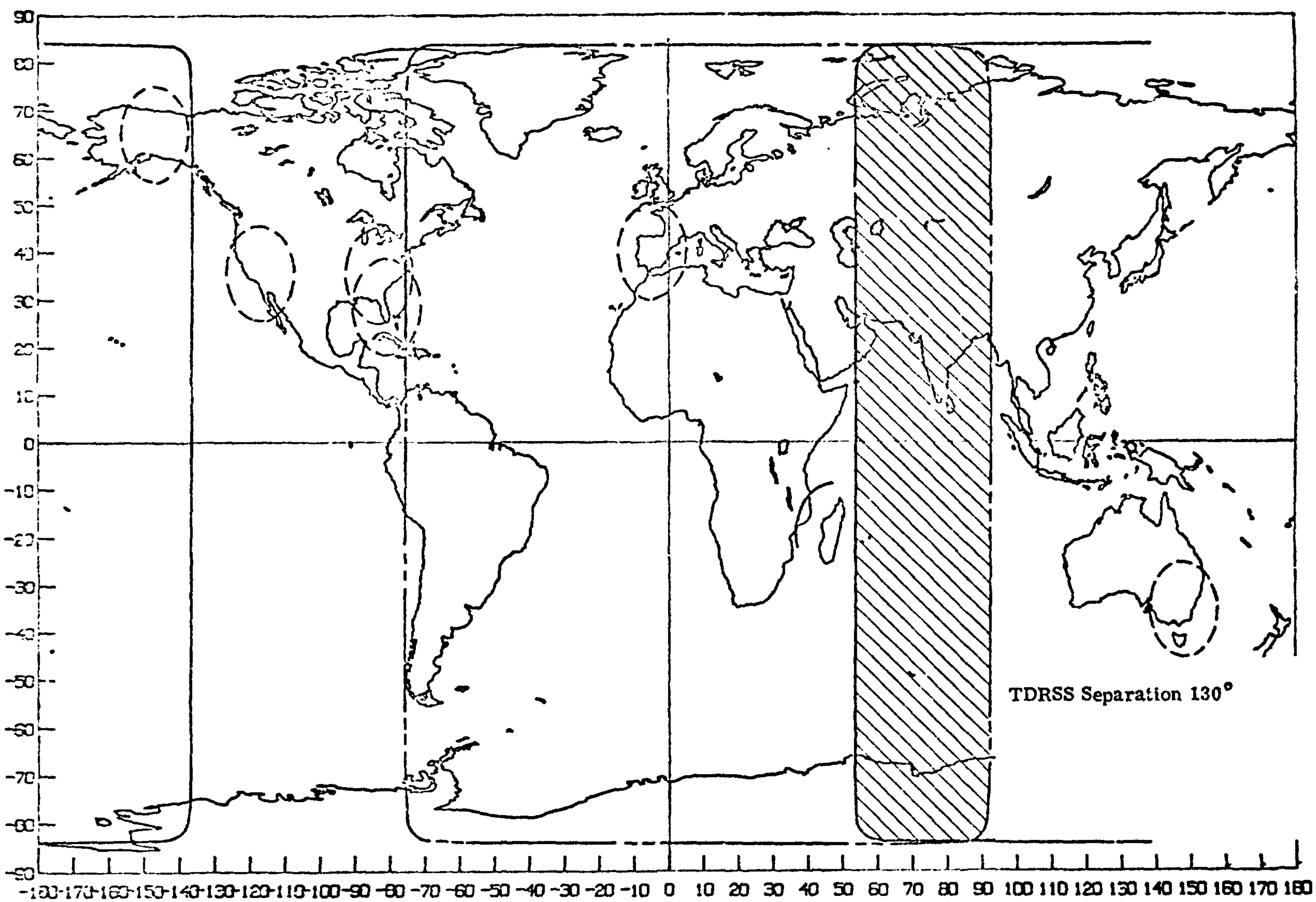


Figure B-3. TDRSS Plus Ground Sites, 200 km

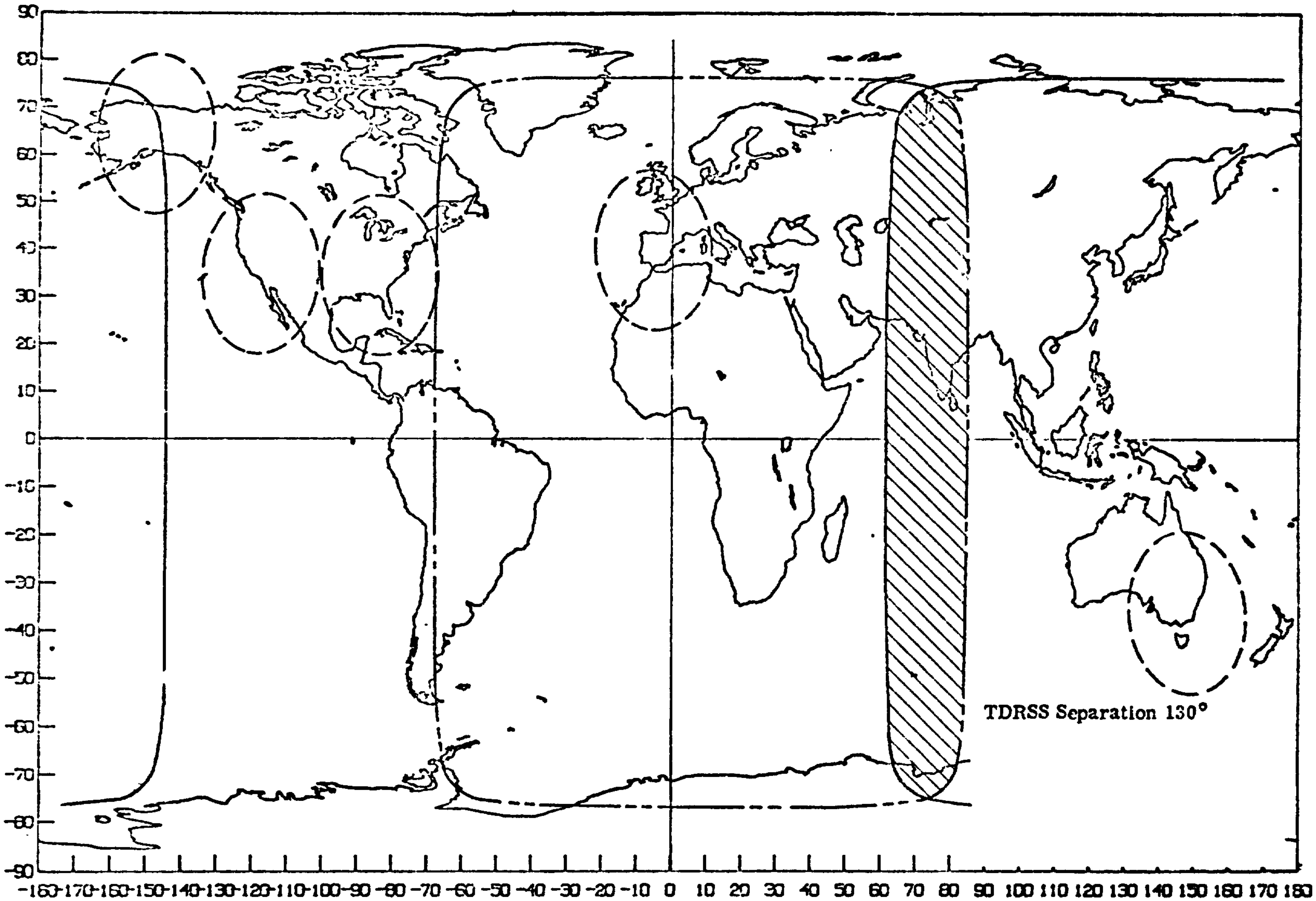


Figure B-4. TDRSS Plus Ground Sites, 500 km

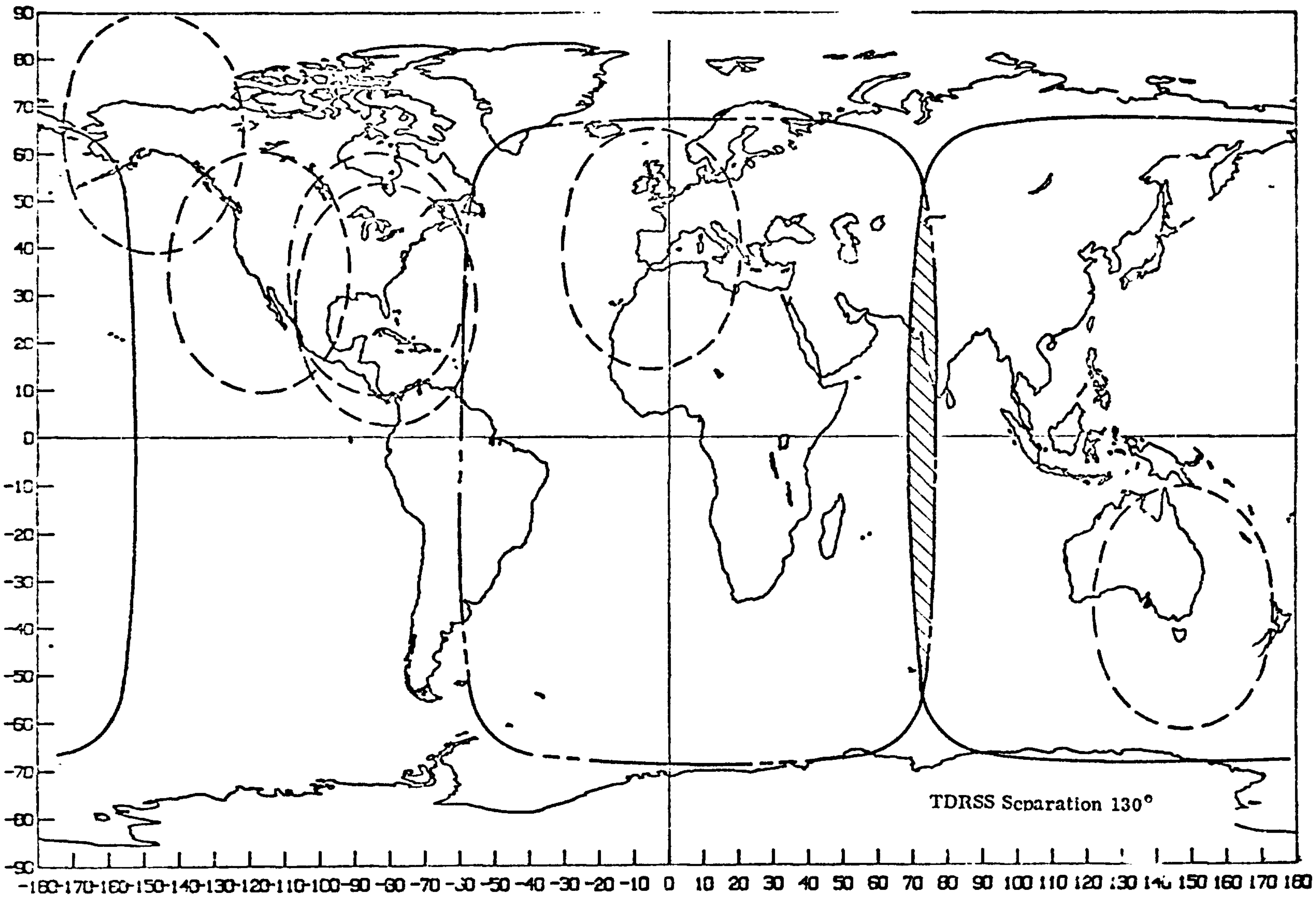


Figure B-5. TDRSS Plus Ground Sites, 1000 km

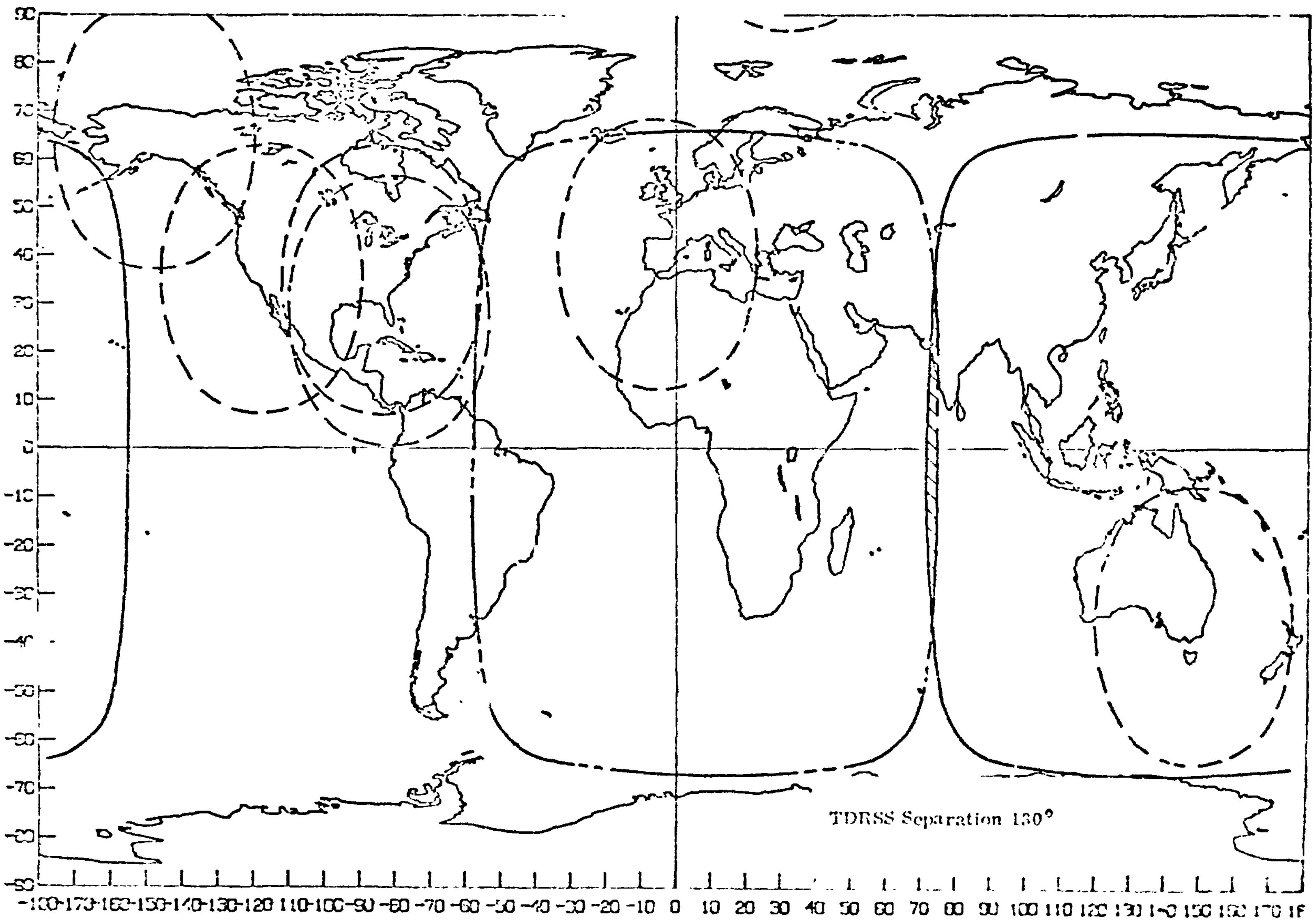


Figure B-6. TDRSS Plus Ground Sites, 1200 km

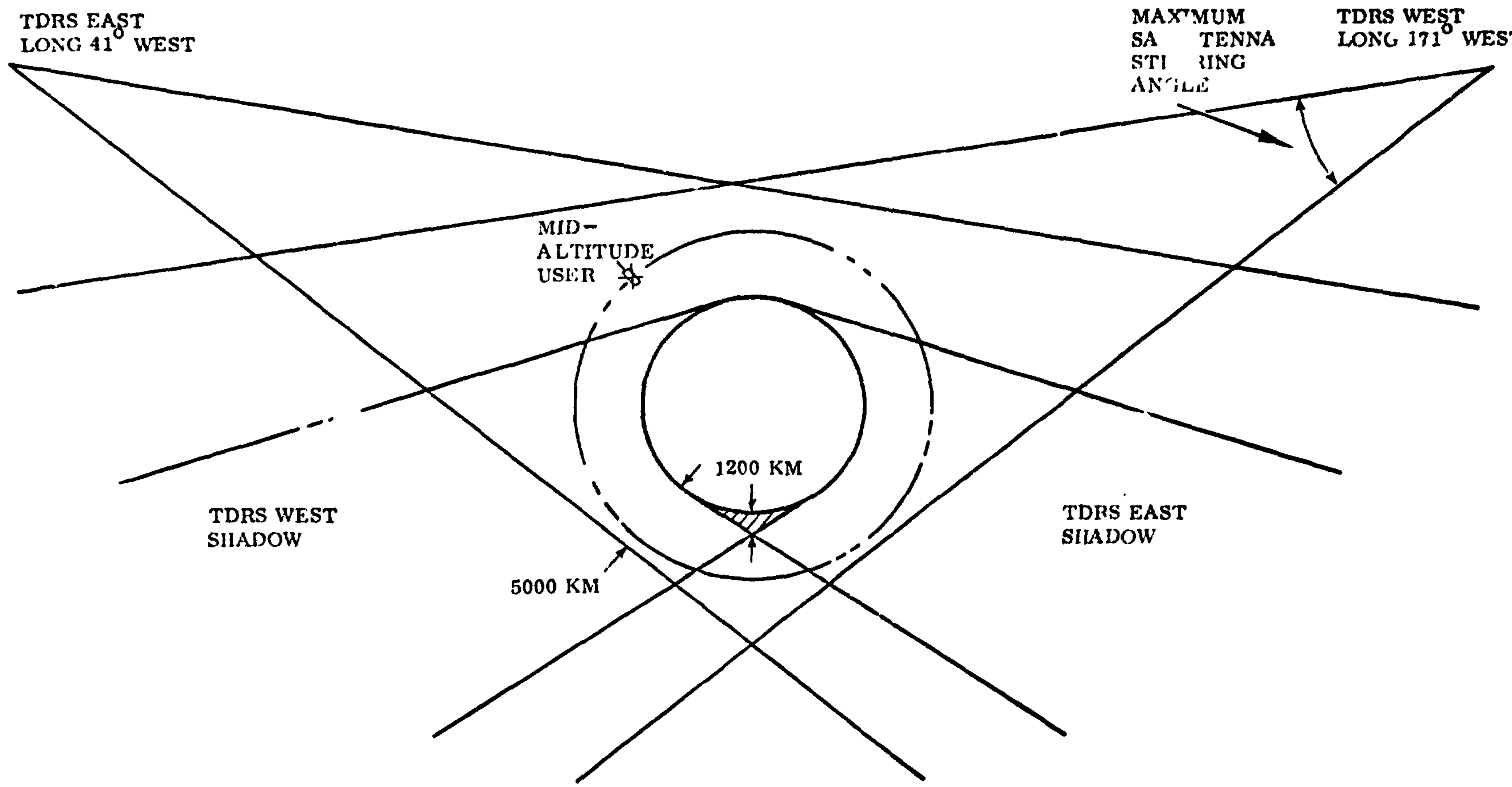


Figure B-7. Mid Altitude Coverage Geometry, 1200 to 12000 km

The following chart defines the symbols and coverage notation used in the mid-coverage zone charts.

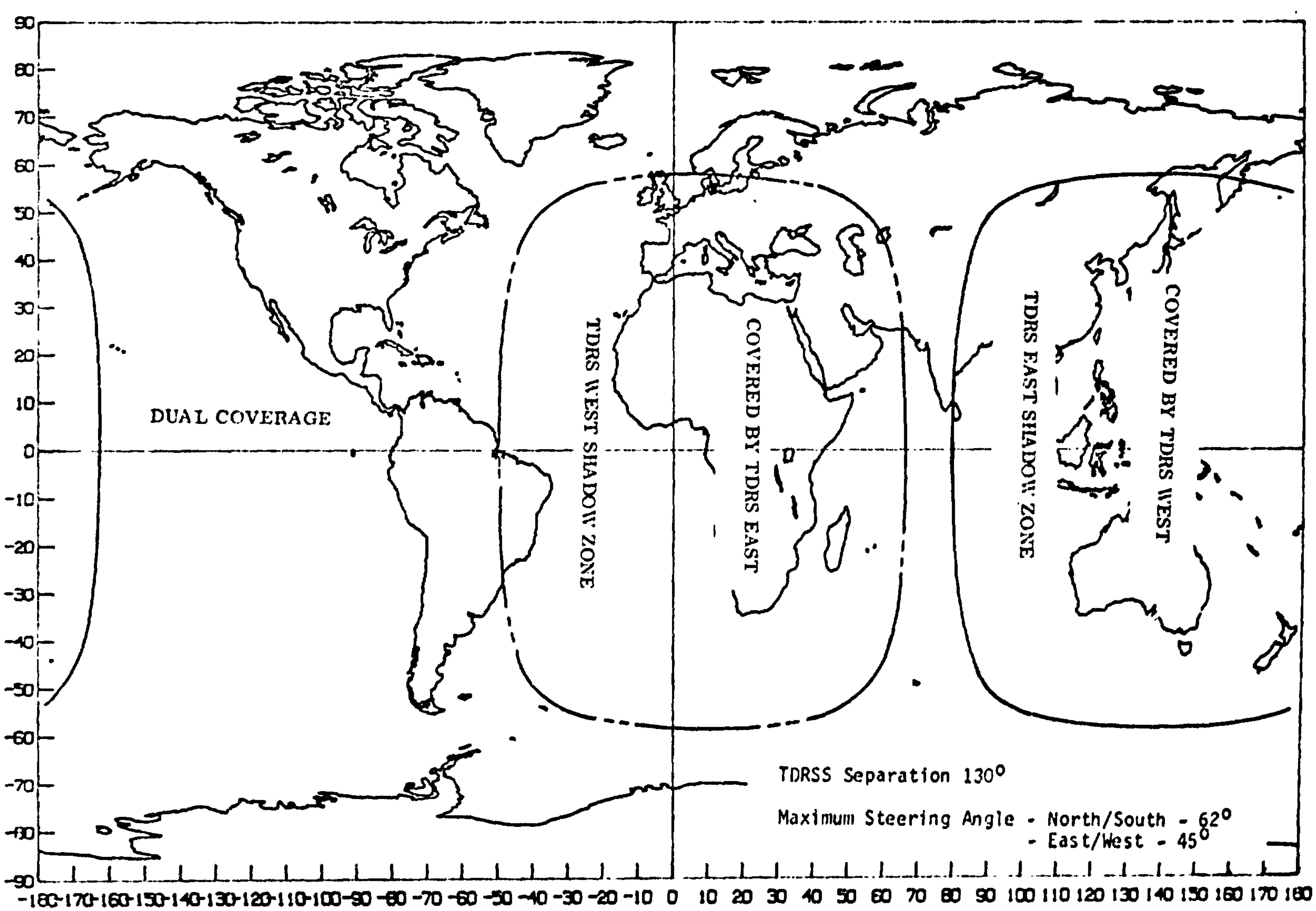


Figure B-8. Mid Coverage Zone, TDRSS Only

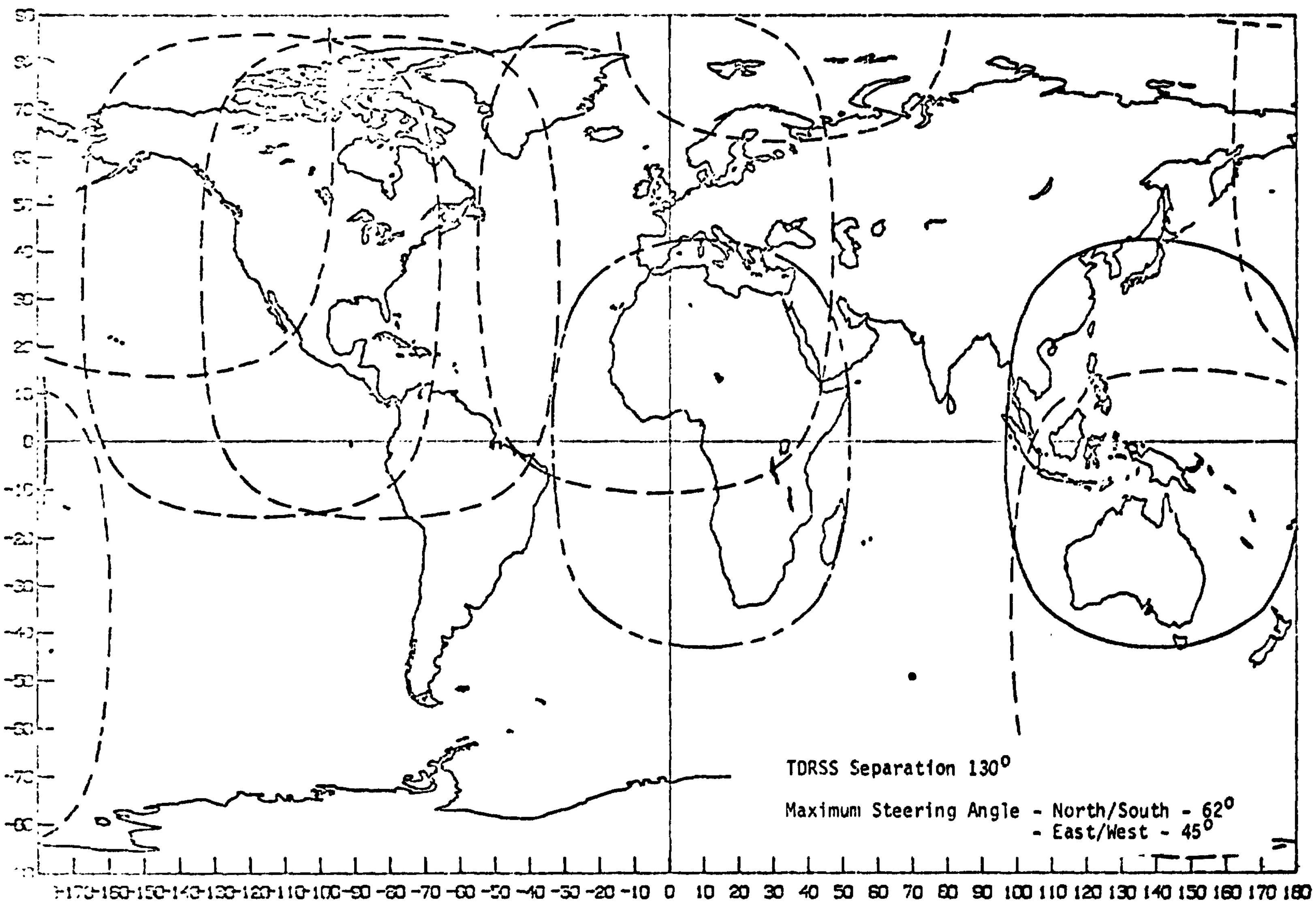


Figure B-9. TDRSS Plus Ground Sites, 5000 km (No Coverage Gaps)

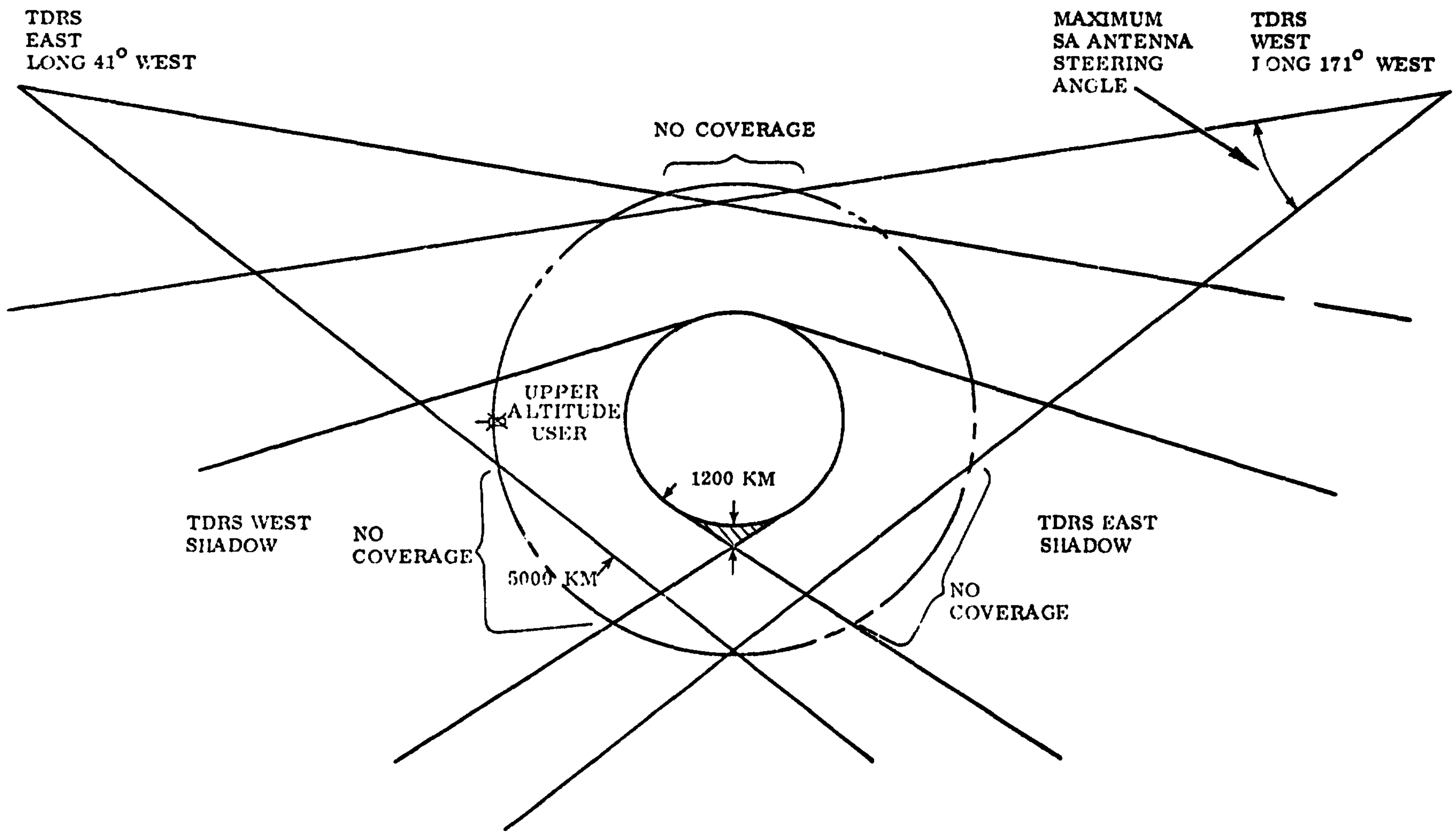


Figure B-10. Upper Altitude Coverage Geometry, Altitude > 12000 km

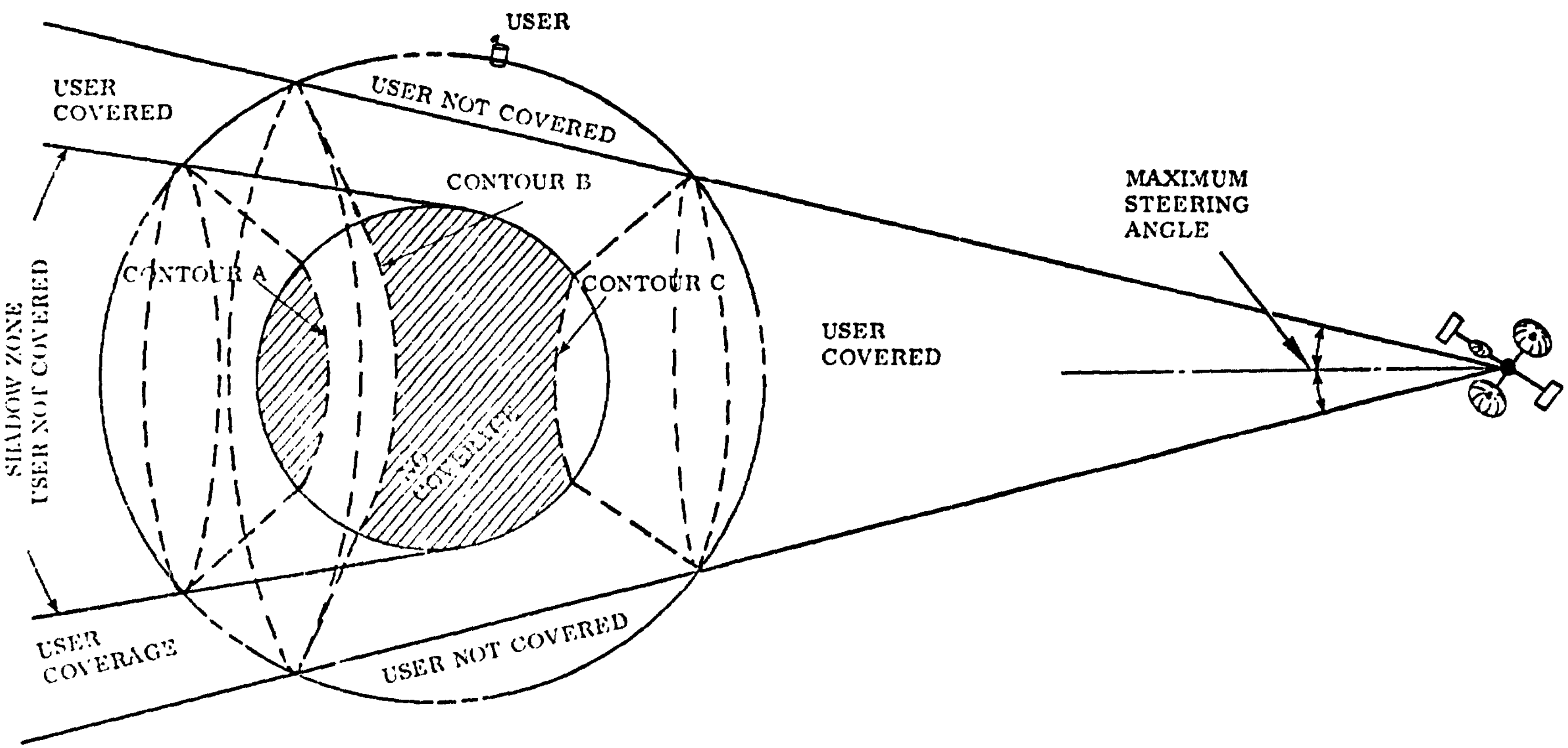


Figure B-11. TDRSS Coverage Geometry

The following four charts define the symbols and coverage notation used in the upper coverage zone charts.

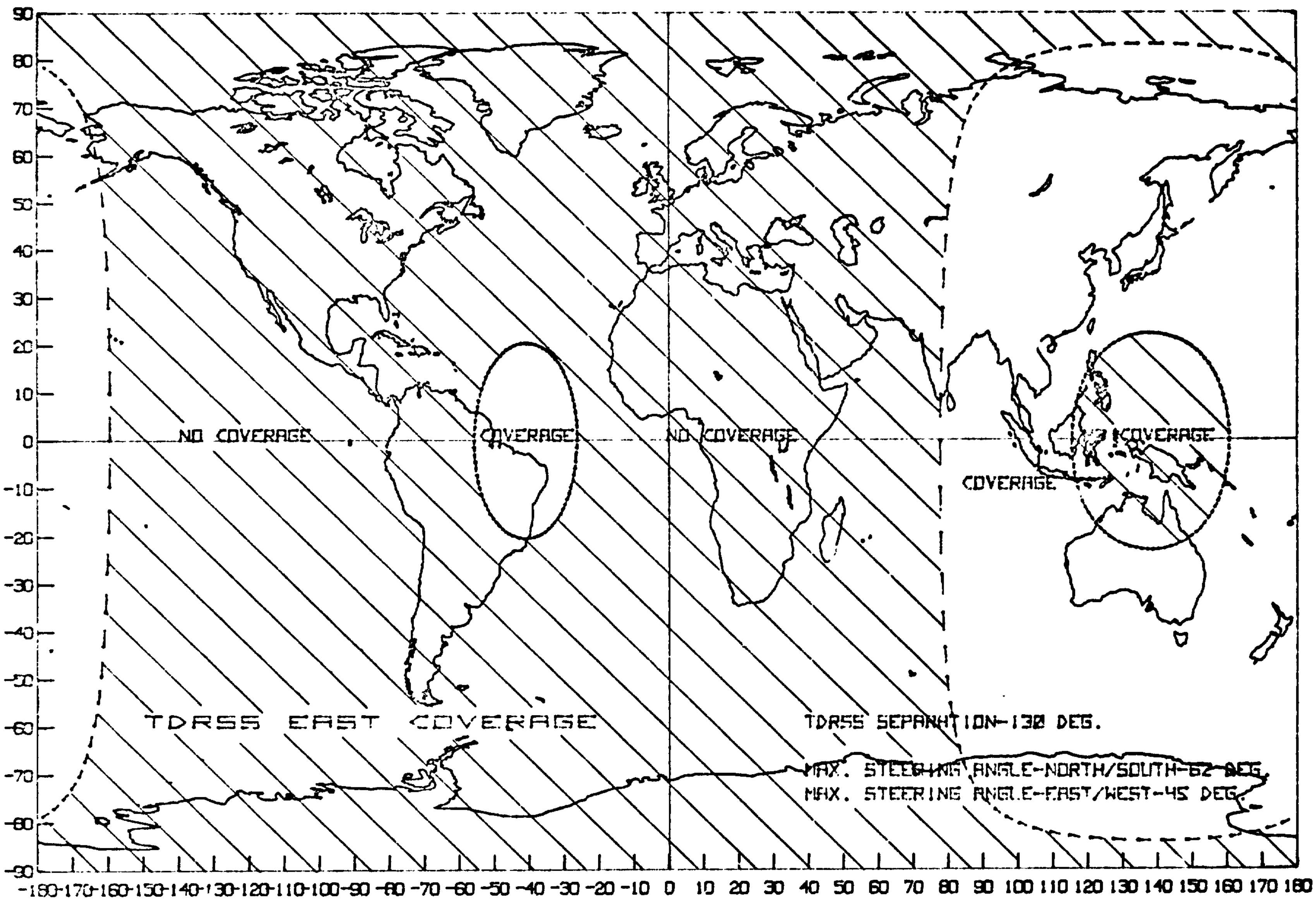


Figure B-12. TDRSS East Coverage

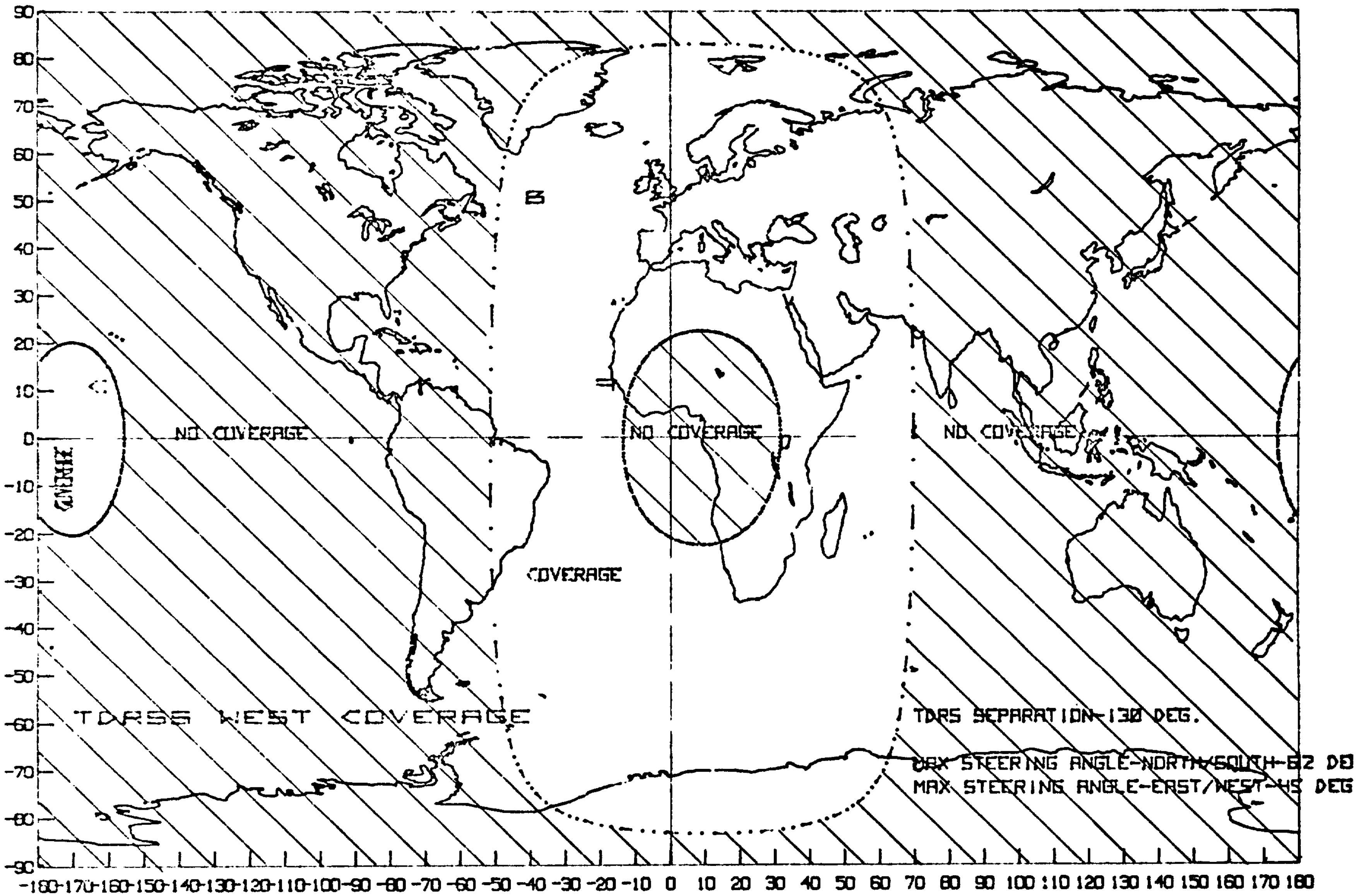


Figure B-13. TDRSS West Coverage

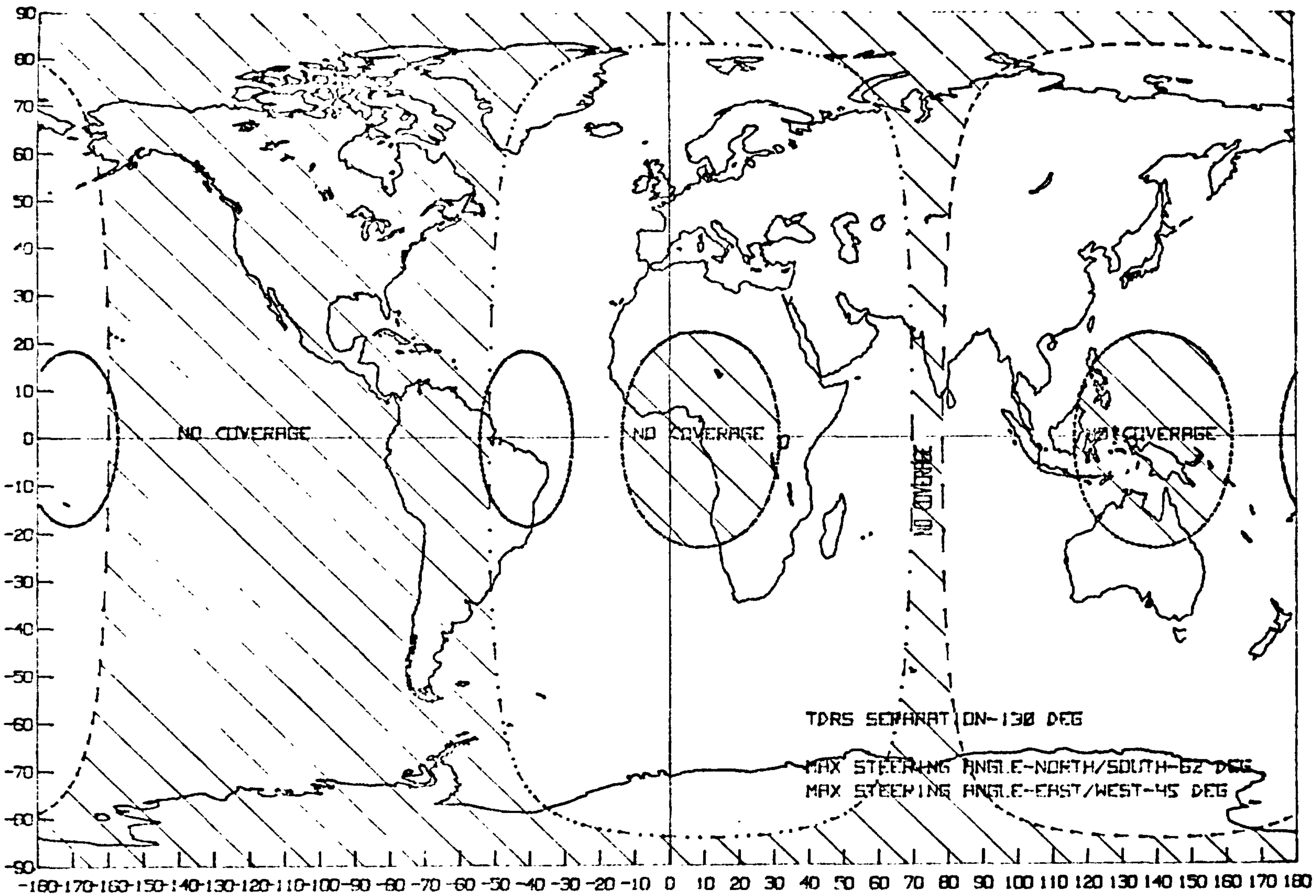


Figure B-14. Upper Zone Coverage, TDRSS Only

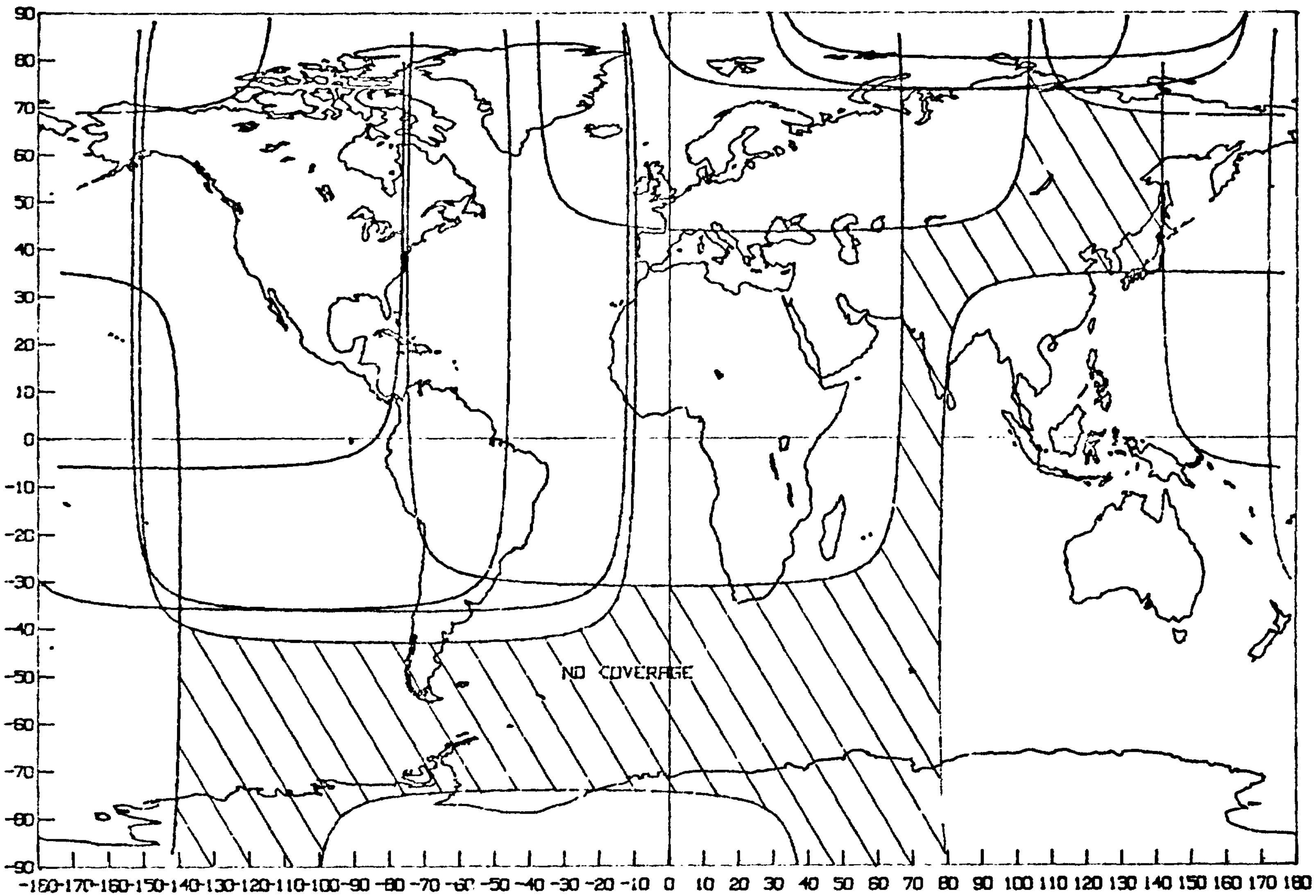


Figure B-15. Ground Sites Coverage

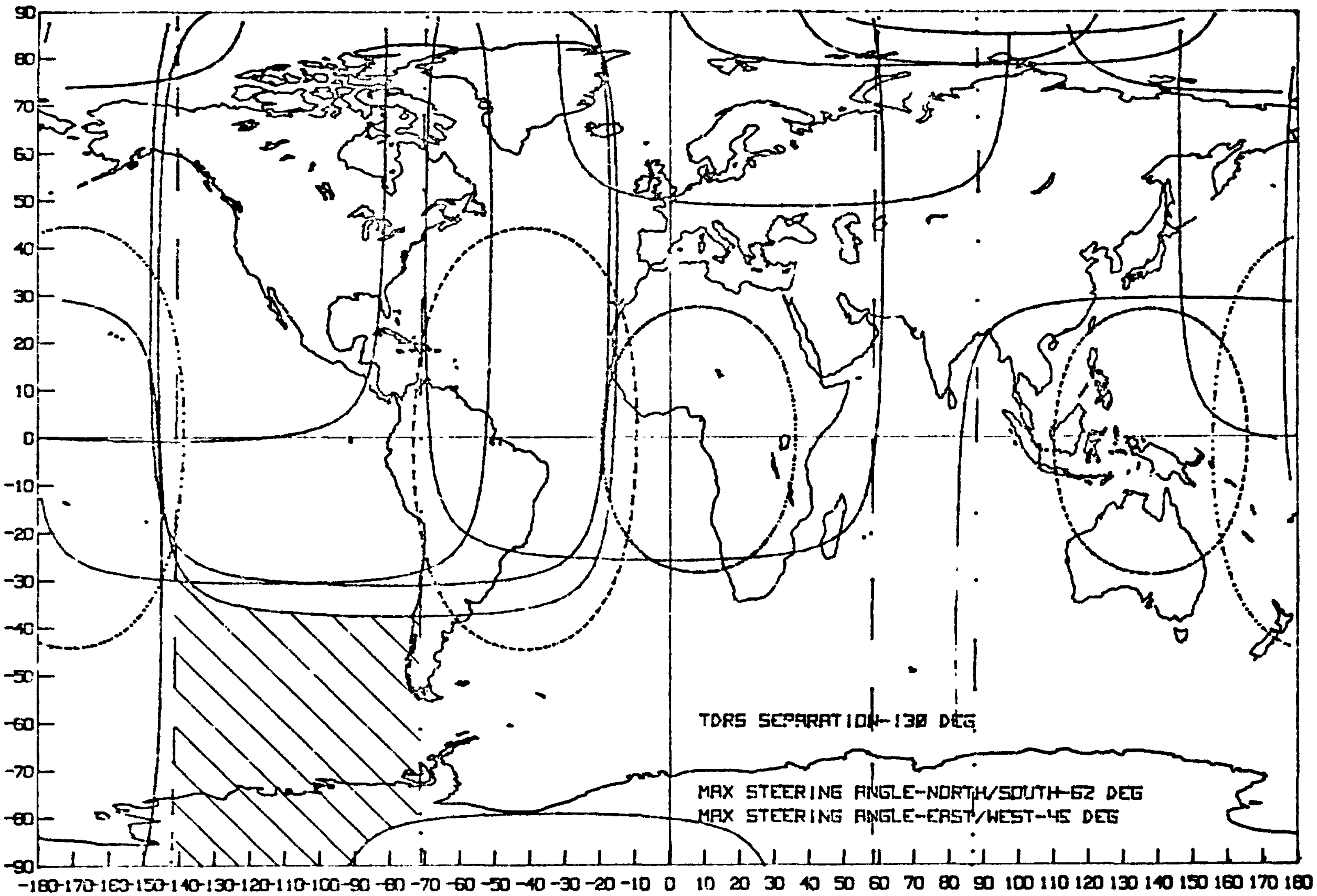


Figure B-16. TDRSS Plus Ground Sites, 13,000 km

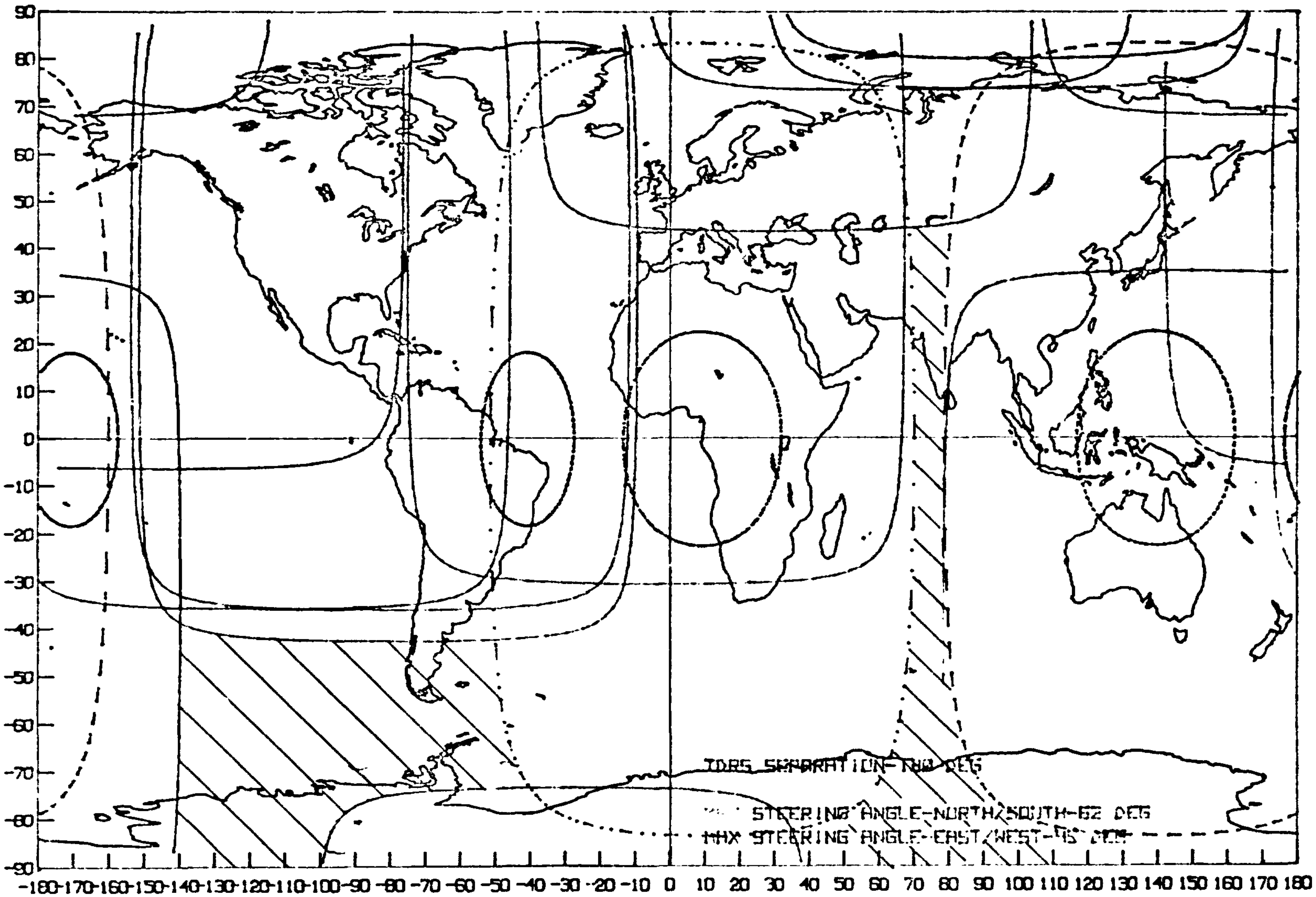


Figure B-17. TDRSS Plus Ground Sites, 20,000 km

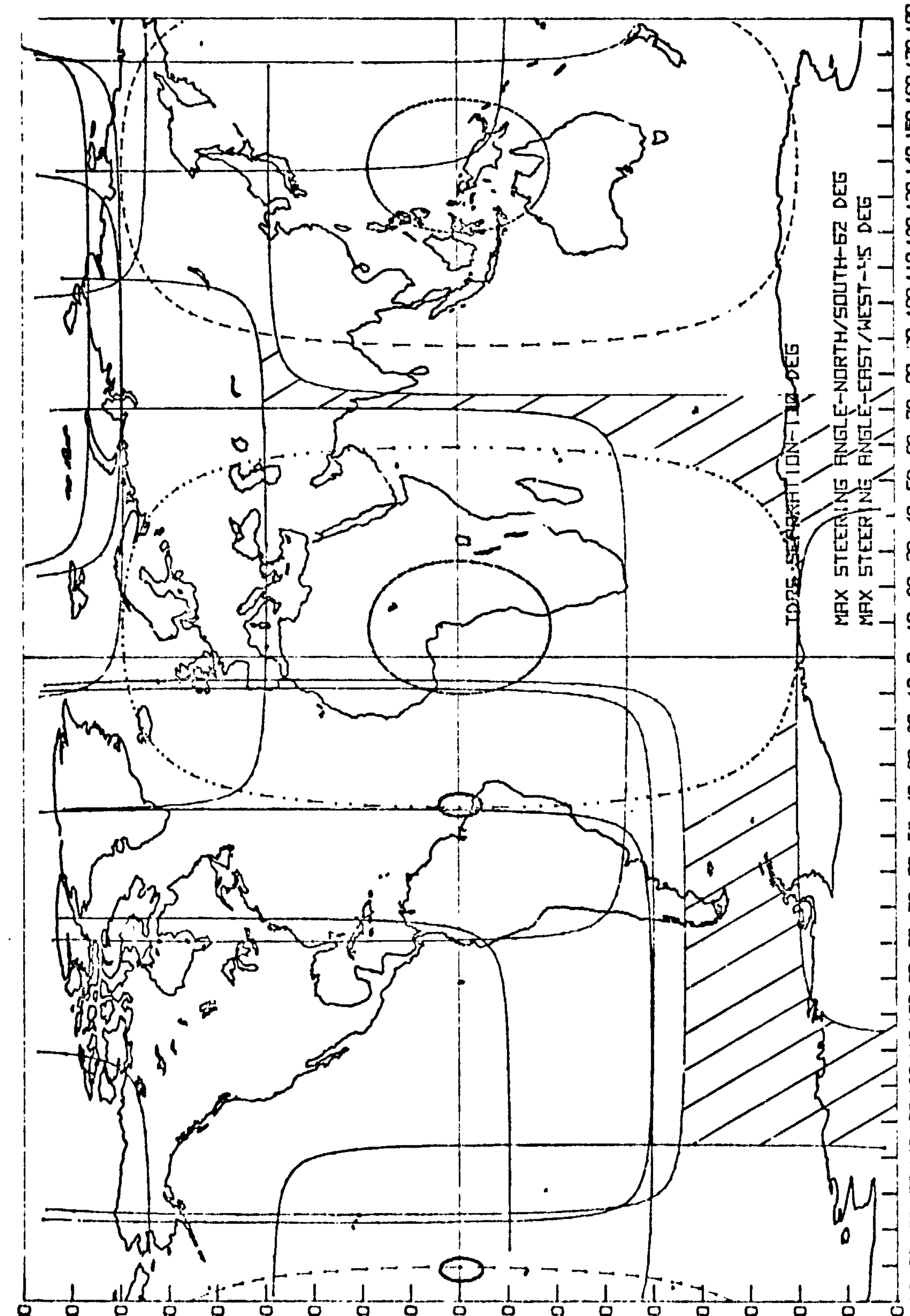


Figure B-16. TDRSS Plus Ground Sites, 30,000 km

APPENDIX C. POTENTIAL USER BENEFITS

1. GENERAL

Some of the potential benefits to the TDRSS subnet users are listed in para 2 and 3. The benefits listed are merely suggestions and should not be considered all inclusive. In general, the TDRSS will reduce network site location constraints on mission planning, reduce or eliminate the need for on-board experiment data storage for most users, and provide the potential for real-time data return (including wideband data) and real-time control for at least 85 percent of each spacecraft orbit.

2. MULTIPLE-ACCESS USERS' BENEFITS

2.1 LONG DURATION COVERAGE

Long duration coverage will provide the following benefits:

a. Considerable reduction in tape recorder requirements for most users, with a maximum of 15 percent of each orbit recorded and played back over the next view period.

b. Real-time command and control, permitting possible reduction of on-board systems.

c. Reduction in requirement for high data rate transmission.

2.2 INCREASED ACCESS TO USER SPACECRAFT

Increased access to user spacecraft will provide the following benefits:

a. Real-time control.

b. In-orbit experiment modification.

c. Real-time receipt of data for at least 85 percent of each user orbit.

d. Near-continuous monitoring and near-instantaneous access, leading to a reduction in the probability of spacecraft failure.

2.3 REAL-TIME DATA TRANSMISSION TO USERS

All data transmission ers will be in real time.

3. SINGLE-ACCESS USERS' BENEFITS

3.1 LONG DURATION COVERAGE

Long duration coverage will provide the following benefits:

a. Reduction in tape recorder requirements for some missions.

b. Reduction in data rate transmission requirements for most missions.

c. Real-time command and control available to some missions.

d. Real-time transmission of high data rate data to users.

3.2 INCREASED ACCESS TO USER SPACECRAFT

Increased access to user spacecraft will provide the following benefits:

a. Reduction in scheduling conflicts for all users.

b. Real-time control for some high priority users and rapid access for all users.

c. In-orbit experiment modification.

d. Continuous access over 85 percent of the earth for experiments with geographical location requirements.

Note

The central Indian Ocean area is not covered.

e. Continuous launch coverage to 5000 kilometers altitude.

3.3 AVAILABILITY OF HIGH-CAPACITY CHANNEL

High capacity channel availability (i.e., up to 300 Mb/s) will provide the following benefits:

a. Potential for real-time transmission to users.

b. Reduction in amount of mission-unique equipment required (1 set).

APPENDIX D. TYPICAL TDRSS USER SUPPORT MODES

Table D-1 lists the various categories of potential TDRSS users and gives a brief description of each. Tables D-2 through D-6 list the type of support, by mission phase, that the STDN can provide to typical users. Table D-7 summarizes, by user class, the type of support that TDRSS can provide. These tables are designed to illustrate the capabilities of the STDN support and assume that each user has a communications terminal adequate for the data rates involved.

Table D-1. Potential TDRSS Users

User Class	Description	Typical Users
1	Users with experiments generating low sample rates (around 1 kb/s).	Explorer class
1A	Scout-launched class; severely weight limited.	SAS
1B	Satellites launched aboard a Delta, or larger, launch vehicle; less severe weight restrictions.	OSO
2	Users with medium sample rates (10's and 100's of kb/s).	HEAO, SATS
2A	Satellites launched aboard a Delta, or larger, launch vehicle; severe weight or EIRP restriction.	
2B	Less severe weight and EIRP restriction.	
3	Users with high sample rates.	EOS, LST, Shuttle
4	Special-purpose, short life vehicles.	Launch vehicles
5	Contingency support, short duration.	Any user

Table D-2. Typical STDN Support Provided to Class 1A and 2A Users (Earth Orbit, < 2000 km)

Mission Phase	Prime STDN Support Subnet	Prime TDRSS Support System[1]	Mission Coverage	Typical Support Configuration
Pad Checkout, Liftoff	Ground Site	---	100%	Real-time, dedicated.
Launch to Insertion	TDRSS	SSA	100%	Real-time, dedicated.
C-band Tracking	Ground Site	---	Undetermined	As required.
Low Earth Orbit (General Requirements)	TDRSS	SSA/MA	Undetermined[2]	SA on priority system, time-shared. Tape recorder dump mode.
Low Earth Orbit (Mission-peculiar Requirements)	Ground Site	---	Undetermined[3]	Reduced support if TDRSS not used.
Synchronous Transfer	---	---	---	
Lunar or Planetary Transfer	---	---	---	
Highly Elliptical Orbit (Low Perigee)	---	---	---	

Note

1. SSA = S-band single access.
   KSA = Ku-band single access.
   MA = Multiple access.
2. Depends on number of SA users.
3. Depends on orbit.

Table D-3. Typical STDN Support Provided to Class 1B and 2B Users (Earth Orbit, < 2000 km)

Mission Phase	Prime STDN Support Subnet	Prime TDRSS Support System[1]	Mission Coverage	Typical Support Configuration
Pad Checkout, Liftoff	Ground Site	---	100%	Real-time, dedicated.
Launch to Insertion	TDRSS	SSA	100%	Real-time, dedicated.
C-band Tracking	Ground Site	---	Undetermined	As required.
Low Earth Orbit (General Requirements)	TDRSS	MA	85% Min	Real-time plus data recorded (if any) in ZOE[2] summed with real-time data.
Low Earth Orbit (Mission-peculiar Requirements)	TDRSS	MA/SSA	100% Except ZOE[2]	Real-time, time-shared, single-access (S- or Ku-band) support.
Synchronous Transfer	---	---	---	
Lunar or Planetary Transfer	---	---	---	
Highly Elliptical Orbit (Low Perigee)	---	---	---	
Contingency	TDRSS	SSA	100% Except ZOE[2]	Time-shared, rapid access.

Note

1. SSA = S-band single access.
   MA = Multiple access.

2. ZOE = TDRSS zones of exclusion.

Table D-4. Typical STDN Support Provided to Class 3 Users (Earth Orbit, < 5000 km)

Mission Phase	Prime STDN Support Subnet	Prime TDRSS Support System[1]	Mission Coverage	Typical Support Configuration
Pad Checkout, Liftoff	Ground Site	---	100%	Real-time, dedicated.
Launch to Insertion	TDRSS	SSA	100%	Real-time, dedicated.
C-band Tracking	Ground Site	---	Undetermined	As required.
Low Earth Orbit (General Requirements)	TDRSS	SSA KSA	Undetermined	Time-shared support, dedication possible to some users.
Low Earth Orbit (Mission-peculiar Requirements)	TDRSS/Ground Site	SSA KSA	100% Except ZOE[2]	Real-time, time-shared, single-access.
Synchronous Transfer	---	---	---	
Lunar or Planetary Transfer	---	---	---	
Highly Elliptical Orbit (Low Perigee)	---	---	---	

Note

1. SSA = S-band single access.
   KSA = Ku-band single access.

2. ZOE = TDRSS Zones of exclusion.

Table D-5. Typical STDN Support Provided to Synchronous Users (Lunar or Planetary)

Mission Phase	Prime STDN Support Subnet	Prime TDRSS Support System	Mission Coverage	Typical Support Configuration
Pad Checkout, Liftoff	Ground Site	---	100%	Real-time, dedicated.
Launch to Insertion	TDRSS	SSA	100%	Real-time, dedicated.
C-band Tracking	Ground Site	---	Undetermined	As required.
Low Earth Orbit (General Requirements)	---	---	---	
Low Earth Orbit (Mission-peculiar Requirements)	TDRSS	MA/SSA	85% Min	Real-time as required, single-access normal.
Synchronous Transfer	Ground Site/TDRSS	SSA	As required	TDRSS subnet to 5000 km, ground site subnet above 5000 km.
Lunar or Planetary Transfer	---	---	---	
Highly Elliptical Orbit (Low Perigee)	---	---	---	

Note

SSA = S-band single-access.
MA = Multiple-access.

Table D-6. Typical STDN Support Provided to Users with Highly Elliptical Orbits

Mission Phase	Prime STDN Support Subnet	Prime TDRSS Support System[1]	Mission Coverage	Typical Support Configuration
Pad Checkout, Liftoff	Ground Site	---	100%	Real-time, dedicated.
Launch to Insertion	TDRSS	SA	100%	Real-time, dedicated.
C-band Tracking	Ground Site	---	Undetermined	As required.
Low Earth Orbit (General Requirements)	---	---	---	
Low Earth Orbit (Mission-peculiar Requirements)	---	---	---	
Synchronous Transfer	---	---	---	
Lunar or Planetary Transfer	---	---	---	
Highly Elliptical Orbit (Low Perigee)	Ground Site/TDRSS	MA	100% Except ZOE[2]	TDRSS subnet coverage, as required, for orbit below 5000 km, ground site subnet above 5000 km.

Note

1. SA = single-access.
   MA = Multiple-access.

2. ZOE = TDRSS Zones of Exclusion.

Table D-7. Type of TDRSS Support Provided, by User Class

User Class	Frequency	Primary Return Link Mode[1]	Primary TDRSS Support System[2]	Secondary (Backup) TDRSS Support System[2]	Comment	Number of Users Anticipated[3]
1A	S	RT or D	SA		Mode D could also be used. Significant increase in number of users would result in D.	2 - 3
1B	S	RT	MA	SA		5 - 7
2A	S	RT or D	SA	MA	Degraded support on MA possible.	2
2B	S	RT	MA	SA		10
3	S, Ku	RT	SA	MA		2 - 3
4	S	RT	SA		Support as required, priority system.	2
5	S, Ku	RT	SA		Support as required, priority system.	
Shuttle	S, Ku	RT	SA		Dedicated support; some support on MA possible.	

Note

1. RT = real-time data transmission (85% coverage)
   D = tape recorder dump (short duration coverage).
2. MA = Multiple-access system.
   SA = Single-access system.
3. Maximum at any time; some users in more than one class.